CLASSIFIED EXAMPLES IN ELECTRICAL ENGINEERING

VOL. I—DIRECT CURRENT

COMPANION VOLUME

Classified Examples in Electrical Engineering

VOLUME II - ALTERNATING CURRENT

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ANSWERS

CLASSIFIED EXAMPLES IN ELECTRICAL ENGINEERING

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DEVONPORT TECHNICAL COLLEGE

VOL. I

DIRECT CURRENT

FOR FIRST AND SECOND YEAR DAY STUDENTS AND FIRST, SECOND AND THIRD YEAR EVENING STUDENTS

IN TWO VOLUMES

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PREFACE

THIS work is just an assembly of questions in electrical engineering arranged under the most important heads in that subject They are taken mainly from the examination papers set during recent years at the London B Sc (Eng) Degree, the A M I E E , the Final City and Guilds and the Whitworth Examinations of the Board of Education, and the author is indebted to the respective authorities (including the Controller, H.M Stationery Office) for permission to reproduce these questions The questions are mainly numerical, but many purely descriptive questions have been included, especially dealing with important principles Notes have been given with many of the sections to help the student, some examples are worked fully in the answers, and references have been given in many instances where the student can obtain further information. There are, of course, other works than those specifically mentioned, wherein information can be obtained, and it does not follow that the references given are necessarily the best, but they will generally be found to be the most accessible Questions have been included in design work, and some data have been given in these sections, but such data are given with reserve, and the student must supplement this data with any other to which he has access The value in design work lies rather more in how to use data when given than in the accuracy of that data It is thus impossible to give answers to the design questions, but many suggestions are given in the answers for the student's guidance

The working of many numerical examples is of great assistance to a student of electrical engineering. Many text-books, therefore, give some examples, but they can only give examples that are covered by the text. This collection of examples is not so restricted, and the references given encourage a student to hunt up information wherever obtainable, and so combines the work of many books and technical publications, and develops that quality of "self-help" so essential in an engineer

Whereas many lecturers will have their own sets of examination questions, it is felt that such a collection as here given in compact form is readily obtainable by the students, and much time can be saved in lectures by reference to these questions instead of dictating such questions to the class, with the added advantage that the student has the question correctly and in permanent form

Vol I deals with the earlier years of the subject and covers the bulk of D C work, including D C machine design

Vol II is more advanced, dealing with more specialized work, and includes A C machinery and transmission and distribution The author is indebted to D G Hitt, Esq, B Sc (Eng), for valuable assistance in getting out some of the answers

S G M

DEVONPORT, 1928

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CLASSIFIED EXAMPLES IN ELECTRICAL ENGINEERING

VOL. I: DIRECT CURRENT

1. Resistances

TAKE the resistance of copper as $7/10^7$ ohms per in ^{3}, or $17/10^7$ ohms per cm ^{3}

EXAMPLES 1

1. Find the resistance of 200 ft. of copper cable having a cross-section of 0 1 sq. in.

2. Find the resistance of 1000 yd. of copper cable 0 3 in in diameter.

3 What length of copper wire 4 mils in diameter will be required to give a resistance of 100 ohms ?

4 A coil of 10 ohms resistance is composed of 100 yd of wire having a diameter of 1 mm. Find the specific resistivity of the material per cm cube

5 If silver has a resistivity of 1 49 microhms per cm. cube, what must be the diameter of a silver wire to have a resistance of 10 ohms per kilometre ?

6 An aluminium cable 5 miles long and 0 1 sq in in section has a resistance of 7 ohms for the double run Find the specific resistivity in inch measure.

2. Ohm's Law and Power

Power

$$\text{Watts} = \text{volts} \times \text{amperes} = \text{resistance} \times (\text{current})^2.$$

EXAMPLES 2

1. What resistance must a consuming device have to run on 200 volt mains and have a loading of 5 kW. ?

2. What voltage is required to pass a current of 35 amperes through a resistance of 5·7 ohms ? If a further 4 3 ohms be

1—(5492)

put in series to reduce the current, find the power lost in the added resistance, and the voltage across the original resistance

3 It is required to run a 60 watt 100 volt lamp on a 230 volt circuit Find the resistance to be placed in series with the lamp to enable this to be done

4. What is the relation between the resistance of a metal filament lamp, taking 60 watts on a 200 volt supply and a carbon lamp taking 60 watts on a 100 volt supply ? If two of the latter in series are run in parallel with the former on a 200 volt circuit, what will be the total current taken from the mains ?

5. An electric iron taking 0 5 kW. on 220 volt mains is found to run hotter than is desired, and a resistance of 10 ohms is put in series with it to reduce the loading By what percentage is the consumption of energy reduced, and what percentage of the reduced load is wasted on the added resistance ?

6. A consuming device of constant resistance works on 250 volt mains, and has placed in series with it a 5-stud regulating resistance with 4 resistance sections between the studs The currents passed when working on the successive studs are 5, 10, 15, 20, and 25 amperes, the latter being on the "all out" stud, i e no external resistance Calculate the values of the resistance sections in order, and the power wasted on the last section, i e. between No. 4 and the "all out" one, when running on each of the first four studs

7 A steel rail used as a conductor for traction work has a weight of 90 lb per yard run, and a specific weight of 0 3 lb per cub in Taking the resistivity of the steel as 6·3 times that of copper, find the resistance per 1000 ft. (neglecting joints), and the loss per 1000 ft when carrying a current of 800 amperes.

3. Energy and Costs

Energy.

Joules = volts × amperes × seconds.
1 unit = 1 kWh = 3,600,000 joules

EXAMPLES 3

1. A radiator running on 230 volt mains is found to take 4 35 amperes. What is its rating, and the cost per hour at 2d per unit ?

2. If a motor takes 185 amperes at 460 volts, and gives 80 h.p , what is its efficiency ? How many B. of T. units will it use per hour ? (*C. & G., I*, 1917.)

3 Why are metal filament lamps more efficient than carbon filament lamps? A metal filament lamp costing 2s 3d gives 25 c p with 30 watts, and is discarded after 500 hours; a carbon filament lamp costing 8d. gives 25 c p with 100 watts, and is discarded after 800 hours Find the cost per 1000 candle-hours, inclusive of lamp renewals, in each case, the price of current being $1\frac{1}{2}$d per B of T unit.

(*C. & G*, *II*, 1915)

4 A current of 150 amperes at 11,000 volts is carried through cable 0 15 sq in cross-section for a distance of 5 miles. What is the yearly cost of the energy lost in the mains (double run) at $\frac{1}{2}$d per unit? What percentage of the power delivered is lost in the line?

5 A motor running on 460 volt mains is found to have an average consumption of 35 amperes for the working period of 48 hours per week If the cost of power is $1\frac{1}{2}$d per unit, find the cost of running this motor for a yearly period of 52 weeks

✓4. Supply Lines. Sizes, Resistance Drops, Weights, etc.

Resistance $R = \rho\, l/a$ $\quad l =$ Length in cm or in
$a =$ Cross-section in cm ^{2} or in ^{2}

For copper $\rho = 7/10^7$ ohms per in ^{3} or $17/10^7$ ohms per cm ^{3}

For aluminium $\rho = 11/10^7$ ohms per in ^{3} or $28/10^7$ ohms per cm ^{3}

Volume $= al = \rho l^2/R$ cub in or cm

Weight Copper ·32 lb per cub in or 02 lb per cub cm. Aluminium ·098 per cub in or ·0058 lb per cub cm

For equal conductivities, aluminium conductor weighs 49 of the copper conductor, and its cross-section is 1·6 as great

Losses due to heating I^2R watts

EXAMPLES 4

1 It is desired to transmit 100 amperes C C. over a distance of 3 miles with a drop not exceeding 50 volts (both lines). Find the minimum cross-section and weight of conductor if of copper. What would these figures have been for an aluminium cable?

2 A 50 b h p. 440 volt C.C. motor has a full-load efficiency of 88 per cent, and is fed through a 2 sq. in cable 1000 yd. long When the motor is running at full load, find (*a*) the volt

drop on the cable, (b) the kW. loss in it, and (c) the weight of copper in it.

3 Over what distance is it possible to transmit and deliver 15,000 kW. at 30,000 volts direct current, through cables 1 sq in. cross-section, with a resistance line loss of 10 per cent of the energy put into the line?

4. A generator feeds a 100 h.p 500 volt C C. motor situated 800 yd. away The motor efficiency at full load is 91 per cent, under which conditions the generator is found to be supplying 90 kW. Find the voltage of the generator and the weight of copper in the lines

5 A cable of uniform section transmits current from a source of supply of 220 volts to a resistance of 12 ohms situated 240 yd away. At a point in the line 160 yd away from the source is a motor which is connected to the line intermittently and takes 10 amperes

Find the resistance per 1000 yd of conductor which may not be exceeded if it is desired to ensure that the switching on and off of the motor will not produce a variation in pressure of more than 2 volts at the end of the line connected to the resistance. (*Whitworth*, 1924.)

6 Power is supplied to a motor at 460 volts situate 800 yd from a generator. The motor gives 120 h p. at an efficiency of 86 per cent, whilst it is observed that the generator is supplying 111 kW. Find the voltage of the generator, the power lost in the cable, and the weight of copper in it. What size of cable would be suitable for this supply?

5. Resistances in Parallel

EXAMPLES 5

1 A resistance of 4 ohms is in parallel with one of 5 ohms, and a p.d. of 2 volts is applied across the pair. Find the total current and the current in each. What is the combined conductance?

2. Resistances of 4, 6, and 8 ohms are in parallel across a 10 volt supply. Find the combined conductance, the total current, and the percentage of this total current that passes through the 6 ohm coil

3. Resistances of 3 and 4 ohms in parallel form one group, and 5 ohms and 6 ohms in parallel a second group, the groups being then placed in series. What voltage must be applied across the whole to pass a total current of 10 amperes, and what power will be absorbed by each resistance?

4 The following four resistance coils are in parallel. 2, 3, 4, and 5 ohms What p d. must be applied to the group in order that a total power of 100 watts may be absorbed? How will this power be divided between the various branches?

5 Resistances of 5, 8, 2, and 4 ohms are together in parallel, and the group is connected in series with coils of 3 and 6 ohms in parallel, and finally a coil of 7 ohms is connected in series with the whole If 20 volts be applied across the extremes, find the current in the 2 ohms branch and the power absorbed in the 7 ohms resistance

6 A galvanometer has a resistance of 171 ohms. Find the value of a resistance to be placed in shunt with the galvanometer so that only one-tenth of the current will now pass through the latter. What would have been the value of the shunt to pass only one-twentieth part of the current?

7 Group A consists of resistances of 4, 6, and 8 ohms in parallel. It is connected in series with group B consisting of 3 and 6 ohms in parallel Across these two series groups is connected a resistance of 5 ohms to form a parallel group, and a further resistance of 7 ohms is placed in series with the whole Find the p d. required across the extremes to get a current of 5 amperes through the 7 ohms resistance Find also the current through the 4 ohms coil and the power absorbed in the 3 ohms coil

8 Define the practical units of current, potential difference and power. Three resistance coils in parallel consume 500 watts when a p d. of 50 volts is applied to them The resistances of two of the coils are 14 and 25 ohms respectively. Find the resistance of the third coil. (*C. & G*, *I*, 1919.)

6. Battery and Resistance Groupings

EXAMPLES 6

1 Four Leclanché cells having an E M F. of 1 4 volts and an internal resistance of 2·4 ohms each are connected (*a*) in series, (*b*) in parallel to a resistance of 2 ohms Find the current in each case.

2 In the above question, find the power used in each case both (*a*) internally, and (*b*) externally to the cells Would any other arrangement of the battery give more external power? If so, how much?

3. Prove that in any arrangement of batteries and resistances, the maximum power output is obtained when the internal and external resistances are equal. Given 6 cells of

E M F 1 3 volts and internal resistance 3 6 ohms each, and 4 resistances of 5 4 ohms each, how will you arrange them to get (*a*) the maximum power output, and (*b*) the maximum current output? Find the current and power outputs in each case

4 Three resistances 2, 3, and 4 ohms respectively, are connected in parallel. In series with these is connected a battery having an internal resistance of 1 ohm, and an E M F. of 6 volts Find the current through each of the resistances 2, 3, and 4 ohms (*C. & G., I*, 1918.)

5 Describe, with sketches, the construction of some good form of dry cell Explain the chemical reactions that occur in such a cell Three such cells in series have a total E M.F of 4 3 volts If the cells each have an internal resistance of 0 3 ohm, and are connected to a lamp having an internal resistance of 8 ohms, what will be the p d at the terminals of the lamp? (*C. & G, I*, 1919.)

6. How would you arrange a battery of 6 cells so as to get a maximum current through a wire of 3 ohms? The E M F of each cell is 1 4 volts, and the internal resistance 2 ohms What is the value of the maximum current?

(*C & G, II*, 1915)

7. Twelve cells giving 2 volts and having an internal resistance of 0 12 ohm each, are connected in series with a group of 3 resistances in parallel of 2, 1, and 0 5 ohms respectively and in series with a further group of 2 in parallel of value 1 and 0·33 ohms respectively. Find the total current when the cells are connected (*a*) all in series, (*b*) all in parallel, and (*c*) such as to give the greatest current possible.

7. Kirchhoff's and Maxwell's Laws

EXAMPLES 7

1. A network is composed of the following resistances: $ab = 3$ ohms, $bc = 5$ ohms, $cd = 2$ ohms, $ad = 4$ ohms, $bd = 8$ ohms. If a pressure of 2 volts is applied between a and c, find the current in each of the resistances.

2. The following resistances are connected up and a pressure of 5 volts applied between a and e: $ab = 2$ ohms, $bc = 2$ ohms, $ac = 3$ ohms, $bd = 2$ ohms, $de = 4$ ohms, $be = 4$ ohms, $ce = 3$ ohms. Find the current in each branch of the network.

3. A pressure of 3 volts is applied between the points a and c in the following network: $ab = 2$ ohms, $bc = 4$ ohms, $ad = 2$ ohms, $dc = 2$ ohms, $ae = 5$ ohms, $de = 3$ ohms, $ec = 4$ ohms. Find the current in each branch.

4 A Wheatstone bridge consists of ab = 4 ohms, bc = 3 ohms, cd = 6 ohms, and da = 5 ohms A 2 volt cell is connected between b and d, and a galvanometer of 10 ohms resistance between a and c Find the current through the galvanometer

5 A battery having an E M.F of 110 volts and an internal resistance of 0 2 ohm is connected in parallel with another battery with an E M F of 100 volts and resistance 0 25 ohm. The two batteries in parallel are placed in series with a regulating resistance of 5 ohms and connected across 200 volt mains. Calculate the magnitude and direction of the current in each battery and the total current taken from the supply mains

(*C & G., Final*, 1927)

6 If a p d of 2 volts is applied to a Wheatstone bridge in which all but one of the arms and the galvanometer have resistances of 1000 ohms, the one arm having a resistance of only 500 ohms, find the galvanometer current

(*Lond. Univ* , 1927, *El Tech.*)

8. Temperature Coefficients

$$R_t = R_o\,(1 + at)$$

where R_t = resistance at a temperature $t°$,
R_o = resistance at 0°,
a = the temperature coefficient, i e the increase in resistance of 1 ohm per degree rise in temperature using the resistance at 0° as the basic value

This coefficient in the case of copper is 0 00428 per degree Centigrade, and five-ninths of this value per degree Fahrenheit, with 32° F as the base For approximate work, it is not necessary to revert to the value at 0° C , the following being sufficiently accurate—

$$R_T = R_t\ \{1 + a\,(T - t)\}$$

where R_T and R_t are the resistances at $T°$ and $t°$ respectively

EXAMPLES 8

1 If a coil of copper wire has a resistance of 10 ohms at 15° C., what will be its resistance at 100° C. ?

2. What rise in temperature would be necessary to increase the resistance of a conductor from 50 to 51 ohms, if the

temperature coefficient of the material comprising the conductor is 0 00268 per degree C ?

3. A coil of copper wire has a resistance of 50 ohms when its temperature is 15° C After a current has been passing through it for some time, it is found that 110 volts are required to pass 2 amperes Calculate the temperature of the coil

(*C & G., I*, 1917)

4 A direct current motor running on mains maintained at a constant voltage of 220 is found to be taking a current of 2·4 amperes through the field when started from the cold, but after running for some hours, the current has fallen to 2 amperes. Calculate the rise in temperature of the coil

5. The resistance of a coil is found by measurement to be 53 7 ohms at 16° C. On being warmed up to 84° C, the resistance is found to be 64 1 ohms Find the temperature coefficient of the metal used for the conductor.

6 It is required to maintain a loading of 5 kW on a heating unit. At the initial temperature of 15° C. a voltage of 220 is necessary for this purpose After the unit has been running long enough to settle down to a steady state, it is found that a voltage of 240 is required to maintain the loading. Given that the temperature coefficient of the conductor is 0 000[illegible] per degree C., estimate the final temperature of the heating element.

9. Magnetic Fields

EXAMPLES 9

1 What will be the strength of the field on the axis of a long bar magnet at a distance of 10 cm. from the pole if the pole strength is 20 units ?

2. What will be the strength of the field at a point 10 cm from the axis of a long straight conductor carrying a current of 20 amperes ?

3. What will be the strength of the field at the centre of a circular conductor of 10 cm. diameter when carrying a current of 20 amperes ?

4. Define the C.G S. unit of current and state its relation to the ampere. A coil of wire 10 cm. in diameter with 15 turns carries a current of 5 amperes. Estimate the strength of the magnetic field produced at the centre of the coil

(*A.M.I.E.E., Oct* , 1923.)

5 Define (*a*) unit magnetic pole, (*b*) pole strength, (*c*) magnetic moment, and (*d*) horizontal intensity of the earth's

magnetic field A magnet of 1440 units and magnetic length 40 cm is placed horizontal and with its north-seeking pole pointing north If the earth's horizontal magnetic intensity is 0 18 dynes, find the distances of the neutral points from the poles of the magnet (*A M.I E E., April*, 1923)

6 A bar magnet of length 10 cm has a magnetic moment of 200 C G S units. What strength of magnetic field would the magnet produce at a point on its axis distant 30 cm from its centre ? (*A M I E.E* , *Oct.*, 1924.)

7. A current is passed through a circular coil consisting of two turns of radius 7 5 cm set vertically in the magnetic meridian. A horizontal magnetic needle at the centre of the coil is deflected through 45° Hence calculate in amperes the current flowing through the coil (The earth's horizontal field = 0 18 gauss.) (*A M I E E* , *Oct.*, 1924)

8 Calculate the strength of the magnetic field at the centre of a square coil of 20 cm. side of one turn carrying a current of 20 amperes

9 If two long conductors placed parallel to one another 4 in apart each carry 1200 amperes in the same direction, calculate the force on each per inch run

10. Magnetizing Coils

$$H = \frac{4\pi SI}{10\,l}$$

where H = the magnetizing force in the solenoid coil,
SI = the ampere-turns in the coil,
l = the length of the magnetic path in cm

Transposing, we have $SI = 10Hl/4\pi = \cdot 8Hl$, which enables the ampere-turns to be calculated for a given magnetic field strength B, which numerically equals H for non-ferrous paths, and equals μH for iron paths, where μ = the permeability of the iron under the given circumstances. For compound magnetic circuits, calculate the SI separately for each portion of the path, and sum results

EXAMPLES 10

1 800 turns of insulated wire are wound on a 5 in. cardboard former, the winding extending over 20 in. length of the tube. If 5 amperes are passed through the winding, find the

value of the magnetizing force produced at the centre of the tube

2. A wooden ring of 15 cm mean diameter, the cross-section (circular) of the wood being 7 06 sq. cm, is wound over with a coil of 100 turns Find (*a*) the value of H at the centre and inner and outer edges of the wood when a current of 2 amperes is passing through the coil, and (*b*) the current required to produce a total flux of 50 lines in the wood.

3 A current of 3 amperes passing through a coil of 400 turns wound on an iron ring of 120 cm mean circumference produces a flux density of 18,000 lines per sq cm. in the iron. Find the permeability of the iron under these circumstances.

4. An iron ring having a cross-section of 8 sq. cm. and a mean diameter of 24 cm, has a radial gap 3 mm. wide cut in it It is desired to produce a flux of 120,000 lines in this gap, no fringing of the flux taking place. If, under these conditions, the iron has a permeability of 1200, calculate the requisite ampere-turns to be placed on the ring.

5. Show the effect of slots on the magnetomotive force needed to send the flux across the air-gap of an electromagnetic machine, and indicate how this is allowed for by Carter's coefficient. Calculate the number of ampere-turns required for the air-gap of an alternator, given gap length = 7 mm.; slot opening = 14 mm; slot pitch = 30 mm.; pole arc = 32 cm.; core length (including 4 ventilation ducts each 1 cm. wide) = 35 cm, flux = 10 megalines. Assume the pole-shoe to be concentric with the armature, and ignore fringing at the edges of the poles

$$\text{Given Carter's coefficient} = 0{\cdot}28, \text{ for } \frac{\text{opening}}{\text{gap}} = 2.$$

$$\text{Given Carter's coefficient} = 0{\cdot}22, \text{ for } \frac{\text{opening}}{\text{gap}} = 1{\cdot}43.$$

(*Lond. Univ.*, 1921, *El. Mach.*)

6. An iron ring having a mean diameter of 30 cm. and a cross-section 4 cm. in diameter, has a radial slot of 2 mm. width cut in it. Given the permeability to be 700, how many ampere-turns will be required on the ring to produce (*a*) a flux density in the gap of 20,000 lines per sq. cm., fringing neglected, and (*b*) a total gap flux of 100,000 lines, neglecting leakage?

7. If the ratio arc/pitch is 0·7 and the leakage factor 1 15, estimate the number of ampere-turns per pole required to

produce a flux of 10 megalines through the air-gap of the machine of which the following particulars are known—

Part	Yoke	Pole	Air-gap	Teeth	Armature Core
Cross-sectional area in sq cm	500	820	1330	590	650
Length of path in cm	40	20 3	0 635	3 6	16

B lines per sq cm	6000	8000	10,000	12,000	14,000	16,000	17,000
H for cast steel	3	5	6	10	17	30	46
H for sheet steel	2	3	4	7	11	30	70

(*A M.I E E.*, *April*, 1924.)

8. A ring is made of cast steel having a mean diameter of 10 in., the section being 2 in. (parallel to axis) by 1 in. (radial) A radial gap $\frac{1}{16}$ in. wide is cut in the ring, and it is wound over with a coil of 150 turns Using the B–H data in the previous question, plot a graph showing the relation between the current in the coil and the flux in the gap.

9 A ring 1 ft mean diameter is made of round iron 1 in. diameter, but at one point a saw-cut 1 mm. wide is made through it. If it is uniformly wound with 500 turns of wire, calculate the current required to produce a total flux of 40,000 lines. Neglect leakage and fringing and assume a permeability of 800 (*Lond. Univ* , 1927, *El. Tech.*)

11. Ballistic Galvanometer Calculations

The quantity of electricity discharged through a ballistic galvanometer, due to a change of flux linking with the search coil connected to the ballistic, is given by—

$$Q = \frac{\text{Linkages changed}}{\text{Total resistance} \times 10^2} \text{ micro-coulombs}$$

The ballistic circuit has to be of high total resistance to reduce the damping (see Section 23), and thus there is usually included in circuit a high resistance. To compensate for this, the number of turns on the search coil has to be increased—which incidentally helps to keep up the resistance of the circuit

EXAMPLES 11

✓ 1 A search coil is inserted in the centre of a long straight solenoid, and connected to a ballistic galvanometer and high resistance coil The data of the apparatus are as follows—

No of turns on solenoid	= 2000	Length of solenoid winding	1 mt
No of turns on search coil	= 200	Resistance of search coil	5 ohm
Mean area of search coil	= 30 sq cm	Resistance of galvanometer	20 ,,
		Resistance of added coil	20,000 ,,

Various currents passed through the solenoid are reversed, giving the following throws (after correcting for damping)—

Current reversed	1	2	3	4	5	amperes
Scale deflection	17 5	35	53	70	88 5	divisions

Plot the calibration curve of the galvanometer

2. Two turns of wire are wound round a field coil on a machine, and connected to the above ballistic galvanometer with a loading resistance, the total resistance of the circuit being 20,000 ohms. When normal field current was broken in the field circuit, a deflection of 70 divisions was obtained on the galvanometer Estimate the pole flux of this machine. When the two turns of wire were laid on the armature so as to embrace the pole shoe, and the field current again interrupted, a throw of 62 5 scale divisions was obtained. Estimate the leakage coefficient for this machine.

3 A constant number of ampere-turns are applied to a variable air-gap which is enveloped with a search coil connected to the above ballistic. The number of turns on the search coil is 400, and the total resistance of the ballistic circuit is 25,000 ohms. The following figures were obtained when the exciting current was reversed for various sizes of air-gap—

Length of gap .	1	2	3	4	5	7	10	15	20	25 mm.
Galvo throw	47 5	41	36·5	33	30	25	18·5	10 5	5·5	2 5 divisions

Plot the curve, showing the relation between length of gap and flux produced in it.

4. Describe a method for finding the *B–H* curves of bar specimens. An iron ring of 3 5 sq. cm. cross-sectional area with a mean length of 100 cm is wound with a magnetizing winding of 100 turns. A secondary coil with 200 turns of wire is connected to a ballistic galvanometer, having a constant of 1 micro-coulomb per scale division, the total resistance of the

secondary circuit being 2000 ohms On reversing a current of 10 amperes in the magnetizing coil, the galvanometer gave a throw of 100 scale divisions. Calculate the flux density in the specimen and the value of the permeability at this flux density.

(*C & G., Final*, 1927)

5 A ring of sheet iron stampings is arranged for plotting of *B–H* loop, having a magnetizing coil of 350 turns, an iron section of 1 sq cm. and a mean diameter of 20 cm A search coil is wound on of 100 turns and connected up to the above calibrated ballistic with a high resistance, so that the total resistance in circuit is 20,000 ohms During the first part of the experiment, the magnetizing current is step by step reduced from its maximum value to the value given in the table, and the corresponding ballistic throws (corrected for damping) are recorded During the second part, the current is taken from its maximum value to a reversed current of the value given in the table, and the throws still recorded. Plot the hysteresis loop, find (*a*) the ergs lost per c c of iron per cycle, (*b*) the watts loss per lb. at 50 cycles, and (*c*) the Steinmetz coefficient Test figures—

Current	4	3	2	1	5	3	2	1	0	− 1	− 2	− 3	− 5	− 1	−2	−3	−4
Throws	0	2	5 5	11 8	18	22 6	25 5	29	33 5	40	49	60	69	81 7	92	97 3	100

12. Inductances

A circuit has a coefficient of self-induction of 1 henry if the passage of 1 ampere produces 10^8 linkages. There will be a coefficient of 1 henry of mutual induction with another circuit if the 1 ampere produces 10^8 linkages with the other circuit.

EXAMPLES 12

1. In Ques. 1 of Ex. 10, find the coefficient of self-induction of the coil, on the assumption that all the flux links with all the turns.

2. In Ques. 2 of Ex. 10, find the coefficient of self-induction of the coil

3. An iron ring of 10 in. mean diameter is made of bar 1 in. diameter, and is overwound with 500 turns of wire. Taking the permeability of the iron as 800, find the inductance of the coil.

4. A ring 18 in. in (mean) diameter is made out of 1 in. diameter round iron of permeability 750. It is uniformly wound

over with two single-layer windings containing, respectivel 700 and 1200 turns Calculate the self-inductance of ea winding and the mutual inductance between them in practic units.

5. The four field coils on a shunt dynamo each produce pole flux of 3 megalines when an exciting current of 2 amper is passed through the 2000 turns on each pole. Assuming th the flux produced is proportional to current, calculate t inductance of the whole field circuit

13. Lifting Magnets

The lifting force of an electromagnet is given by

$$F = \frac{B^2a}{8\pi} \text{ dynes} = \frac{B^2a}{112 \times 10^5} \text{ lb} = \frac{B^2a}{2\,47 \times 10^7} \text{ kg per pol}$$

where B = flux density in gap of contact in lines per sq cı

a = cross-section area of the pole piece in sq. cm

Fringing and leakage is neglected, and the gap of conta has frequently to be estimated roughly The force is th double the above for the horse-shoe or concentric ty of magnet.

EXAMPLES 13

1. If an electro-magnet of the horse-shoe type is capable lifting a load of 1 ton when working at a gap density of 14,0 lines per sq. cm , calculate the cross-section area of the ir at the pole faces

2 A horse-shoe magnet is formed out of a bar of wrough iron 18 in. long having a section 1 in square. Exciting coils 500 turns each are placed on each limb and connected in seri Find the exciting current that will just hold a load of 150 l assuming a gap of contact of 1 mm., a permeability of t wrought-iron of 700, and neglecting the reluctance of t magnetic path in the load.

3. Show that the energy stored per c c. in a magnetic fie is given by $B^2/8\pi$, and thus deduce the formula for the liftı power of an electro-magnet. An anchor ring of mean diamet 15 in. is cut in two in an axial plane, the two halves bei separated by air-gaps of 15 mils each. If 2500 ampere-turns a applied to the iron, the permeability of which may be tak as 600, find the force necessary to hold the two halves apa The iron is square bar of 1 in. side.

4 A smooth-core armature, working in a four-pole field magnet, has a gap (from iron to iron) of 0 5 in The area of surface of each pole is 1 sq. ft. The flux from each pole is 7 megalines. Find (*a*) the mechanical force with which the pole attracts the armature, (*b*) the amount of energy expressed in joules that is stored in the four gaps

(N.B.—746 joules = 550 ft -lb., 1 ft = 30 48 cm., 1 lb = 453 6 grm) (*C & G.*, *II*, 1909.)

5 (1) Show what relationship exists between the magnetic density at the contact surfaces of two iron surfaces which touch one another and the pull necessary to separate them

(2) A simple lifting magnet is made from a bar of iron 50 mm square section, bent to shape shown in Fig 1

What flux per pole would be necessary in order that the magnet should be capable of lifting a load of 340 kg.? What would be approximately the minimum thickness of wrought-iron plate on which the magnet could exert this pull?

(*Whitworth*, 1925)

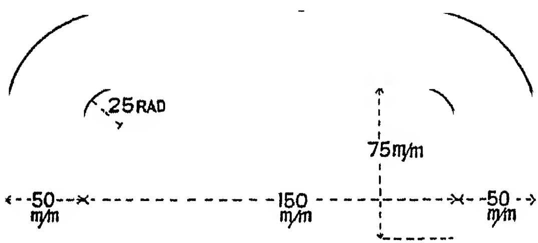

Fig 1

6 Calculate the ampere-turns required for the magnetizing coil of the lifting magnet shown in Fig 1, in order to produce a flux of 360,000 C.G S. lines. In the calculation neglect the reluctance of the keeper and assume that the pole surfaces are separated from the keeper by a sheet of non-magnetic material ½ mm. thick.

The following points on the *B–H* curve of the iron may be useful—

B . .	12,000	13,000	14,000	15,000
H . .	4 5	5 9	8·4	14·2

(*Whitworth*, 1925)

7 Deduce an expression for the energy stored in a magnet field in terms of B and H and the volume of the field. Appl this expression to determine the force required to separat two surfaces with 100 sq. cm. of contact area when the flu density normal to the contact surface is 10,000 lines per sq. cm

(*C. & G., Final*, 1927.)

14. Hysteresis

EXAMPLES 14

1. The connection between the magnetizing current and flu for a particular alternating current electro-magnet is shown b the following table, which gives values for one half of th magnetization loop, the complete loop showing the usua symmetry with respect to the axes

Flux (kilolines)	0	30	75	120	150	170	176	165	138	102	60	0
Magnetizing current (amps)	5.5	6.25	8.0	10.5	14.25	20.5	13.5	6.8	0	-3	-4.5	-5.5

Plot the loop on squared paper and by its aid deduce and plot the wave form of the magnetizing current when the flux follows a sine law, the amplitude of the flux being equal to the maximum value of the flux in the above magnetization loop

(*Lond. Univ.*, 1921, *El. Power.*)

2. Draw the hysteresis loop for transformer iron when B maximum is 11,000 C.G.S. lines per sq. cm. Show how to find the wave form of the magnetizing current when B follows the law 11,000 sin $314t$. If you are given the mean length of the magnetic path and the number of turns in the primary winding, how would you find the R.M.S. value of the magnetizing current and the phase of the current? (*C. & G., Final*, 1920.)

3. A ring of transformer iron stamping was tested for hysteresis loss and gave the following figures

B max.	608	3780	7970	13,410
Ergs per cycle per c.c.	322	725	2375	7950

From the above data find three values of the Steinmetz coefficient, and explain why the Steinmetz equation fails when very high values of the flux density are in question.

(*C. & G., Final*, 1920.)

15. Electrostatic Fields and Capacity

Capacity defined as the ratio of quantity, Q, to voltage, V, i e $Q = C V$

One coulomb of electricity will raise the plates of a condenser of 1 *farad* capacity to a p d of 1 *volt*

V, the p d, = work done on unit charge in being carried from one plate to the other

= intensity of field × distance carried = $F \times d$

If σ = charge per unit surface, then the number of electrostatic lines radiating from this unit area will be $4\pi\sigma$ in air, and $4\pi\sigma/\varepsilon$ in any other dielectric whose specific inductive capacity (S I C) or dielectric constant is ε

1 *Parallel Plate Condenser* For large plates, the field will be uniform, and its intensity will be $4\pi\sigma/\varepsilon$ as above. If the plates are d cm apart, then the p d or work done on unit charge taken from plate to plate will be $4\pi\sigma d/\varepsilon$, and the capacity per unit surface of plate is

$$C = \frac{q}{V} = \frac{\sigma\varepsilon}{4\pi\sigma d} = \frac{\varepsilon}{4\pi d}$$

If A is the area in sq cm of one of the bounding surfaces, then $C = \dfrac{A\varepsilon}{4\pi d}$ cm. (see below for units)

For a multiple plate condenser, arranged alternately + *ve* and – *ve*, A is the area of both sides of one set of plates, or one side of both sets of plates Alternatively, it is the total cross-section area of dielectric through which the electrostatic flux passes

2 *Coaxial Cylinders* (as in a cable), with radii of dielectric r (inner) and R (outer)

If q = charge per cm. length of the cylinder, $= 2\pi r\sigma$, the intensity of the field at the inner surface

$$= \frac{4\pi\sigma}{\varepsilon} = \frac{4\pi}{\varepsilon}\cdot\frac{q}{2\pi r} = \frac{2q}{\varepsilon r}$$

This intensity will thus fall off in inverse proportion to the increase in radius, so that at any point x from the centre it will be $2q/\varepsilon x$ Hence the p d

$$= V = \int_r^R \frac{2q}{\varepsilon x} dx = \frac{2q}{\varepsilon} \log_e \frac{R}{r}$$

Thus the capacity per unit length

$$= C = \frac{q}{V} = \frac{\varepsilon}{2\log_e R/r}$$

3. *Two Parallel Wires* (as in overhead lines) The field surrounding either wire will be similar to that around the centre conductor in the cable above, and the same formulae for intensity and p d will hold good But the second wire is usually at a definite potential, equal but opposite in sign to the first, and the total work done in taking unit charge from one to the other is double that due to one alone. Thus

$$V = \frac{4q}{\varepsilon} \log_e \frac{s}{r},$$

where s is the spacing apart of the wires, and r the radius of the wire.

Hence the capacity per unit length

$$= C = \frac{\varepsilon}{4 \log_e s/r}$$

Units. The C G.S. electrostatic unit of capacity is the "centimetre" (nothing to do with the unit of length), and is first converted to electro-magnetic units by dividing by 9×10^{20}, and then by multiplying by 10^9 to convert to practical units, giving the capacity in farads This is a very large unit, and if we use micro-micro-farads ($\mu\mu$F.), we must multiply by $10^6 \times 10^6$

Hence "cm." of capacity $\times \dfrac{10^9 \times 10^6 \times 10^6}{9 \times 10^{20}}$

$$= \text{“cm.”} \times \frac{10}{9} = \text{“cm.”} \times 1{\cdot}11\mu\mu\text{F.}$$

Thus all the results above are in "cm.," and when multiplied by 1·11, or 10/9, will give the corresponding capacity in practical micro-micro-farads

(*Note.*—The 0 0003 variable condenser as used in radio sets for tuning has thus a capacity of $300\mu\mu$F)

Energy stored $= \frac{1}{2}CV^2$ joules if C in farads and V in volts

EXAMPLES 15

1 Describe the construction of an electrostatic condenser State (*a*) the advantages, and (*b*) the possible disadvantages of using glass as the dielectric An air condenser of capacity 0 001 microfarad is required Calculate the total area of plates, assumed 0 5 mm apart, which would be necessary. (1 microfarad = 900,000 electrostatic units)

(*A M.I.E.E* , *Oct* , 1924.)

2. Calculate the capacity of a parallel plate condenser, the total area of each set of plates being 1600 cm ^{2} and their distance apart 1 mm. (Dielectric, air)

(*A M I E E* , *Oct* , 1925)

3. A parallel plate condenser has its plates 0 2 mm. apart, with solid dielectric between, having a dielectric constant of 3 3 The condenser is charged so that the surface density is 4×10^{-10} coulombs per cm ^{2} Find the electric flux density and the voltage between the plates. (1 coulomb $= 3 \times 10^9$ electrostatic C.G S units)

4 A condenser consists of two co-axial cylinders, the outer diameter of the inner cylinder being 5 cm. and the inner diameter of the outer cylinder being 5 5 cm , and it is 1 metre long If the space between is filled with bakelite having a dielectric constant of 4, calculate the capacity and the quantity of electricity required to charge it to 20,000 volts

5. Calculate the capacity between two telephone wires 1 mile long if they are 0·5 cm. in diameter, and are spaced uniformly 9 in. apart.

6. A submarine cable is 3000 kilometres long. The inner core is 0·4 cm. diameter. The outside diameter of the gutta-percha (S I.C. 4·05) is 1 cm. Calculate the capacity of the cable.

(*A.M.I.E.E.*, *Oct.*, 1923.)

7. A parallel plate condenser is comprised of two metal sheets 1 ft. square, with a dielectric in two layers of 0 1 in. thickness and S.I.C. of 3 and 0 2 in thickness with S.I.C. of 5. If a p d. of 1500 volts is maintained between the plates, calculate the energy stored in the dielectrics and the voltage gradients in them.

16. Electro-Chemistry

Standard 1 coulomb of electricity deposits ·001118 grm of silver

Atomic Weights The number of times the atom of the element is heavier than the atom of hydrogen Thus silver 107·98, nickel 58·7, copper 63·5, etc

Valency The relative electrical charges carried by the atom. Hydrogen, silver, etc , are monovalent, their atoms carrying a certain (minimum) quantity of electricity Nickel is divalent, its atom carrying twice this quantity

Double Valency Copper is monovalent in cuprous compounds, e g cuprous chloride, $CuCl$, while it is divalent in cupric compounds, e g cupric chloride, $CuCl_2$

Chemical Equivalents An atom of a divalent element is equivalent in its combining or charge-carrying properties to two atoms of a monovalent element The following gives the corresponding combining weights or chemical equivalents—

Hydrogen .	1
Silver	107·98
Copper (cuprous)	63·5
Copper (cupric)	31·8 (i.e 63·5 ÷ valency)
Nickel .	29·9 (i e 58·7 ÷ valency)

Electro-chemical Equivalents, i e the weights deposited by one coulomb of electricity, are obviously proportional to the chemical equivalents. Thus the electro-chemical equivalent of nickel would be

$$\frac{\cdot 001118}{107 \cdot 98} \times \frac{58 \cdot 7}{2} = \cdot 000302 \text{ grm. per coulomb}$$

Faraday's Law. The electro-chemical equivalents of all substances are in the same proportion as their ordinary chemical equivalents

EXAMPLES 16

1. How may currents be measured by the electro-deposition of metals? How many coulombs would it take to deposit 10 grm. of metal from a copper-sulphate solution, and what current would be required for 1 hour? The electro-chemical equivalent of copper may be taken as 0·000329 grm. per coulomb. (*A.M.I.E.E., April*, 1925).

2 Explain what is meant by the statement that the electro-chemical equivalent of silver is 0 001118 grm per second * If the electro-chemical equivalent of copper is 0 000328, find how much current must be used to deposit 3 grm of copper on a surface which is being copper-plated, in half an hour

(*A M I E E* , *Oct.*, 1923)

3. State Faraday's laws of electrolysis, and define electro-chemical equivalent A current of 5 amperes passed through a vat containing silver nitrate deposits 6 71 grm of silver in 20 minutes. Hence calculate the electro-chemical equivalent of silver (*A.M I E E.*, *Oct* , 1924)

4 A current of 40 amperes at 5 volts is passed through an electrolytic solution of resistance 0 05 ohm Calculate (*a*) the power spent in chemical action within the cell, and (*b*) the number of calories of heat set free within the cell in 15 minutes

(*A.M.I.E E.*, *Oct* , 1925)

5 Give the legal definition of the ampere, and describe an experiment for calibrating a low-reading ammeter by means of electro-deposition, specially mentioning any precautions to be observed A weighed copper plate was made the cathode in a copper sulphate voltameter, and was connected in series with an ammeter and source of supply A current maintained at 0 6 amperes as recorded by the ammeter was passed for a period of half an hour, and it was then found that the plate had gained 0 36 grm. in weight Given that the atomic weight of copper is 63 and the electro-chemical equivalent of hydrogen as 0 0000104, find the percentage error of the ammeter

6 For the purpose of repairing a worn steel pin, 6 in diameter, 12 in. long, it is required to deposit upon its surface 1 mm. thickness of nickel. The available current is 50 amperes How long must it be continued ? The density of nickel is 8 9, its atomic weight 58 7, and it is divalent in the solution used. The chemical equivalent of silver is 107 98, and ·001118 grm. are deposited per ampere per second

(*Lond Univ.*, 1924, *El. Tech*)

7 State Faraday's law of electrolysis. What do you understand by the electro-chemical equivalent of an element ? If a current is passed through two electrolytic cells in series, one containing cupric chloride ($CuCl_2$) and the other cuprous chloride ($CuCl$), explain what happens in respect to the relative amounts of copper and chlorine deposited or liberated in the two cells. (*Lond. Univ* , 1925, *El Tech*)

* More correctly, per coulomb

17. Illumination

Lambert's Law The horizontal illumination due to a lamp of J candle-power produced in a working plane h feet vertically beneath the lamp, and at a point the direction of which from the lamp makes an angle α with the vertical, is given by

$$J \cos^3 \alpha / h^2 \text{ candle-feet}$$

To produce a given illumination, the following formulae are available—

$$\text{C P} = \frac{\text{Area in sq ft} \times \text{foot-candles required}}{\text{[illegible] lamps}}$$

$$\text{or} \quad = \frac{\text{Area in sq ft} \times \text{foot-candles required}}{5 \times \text{No of lamps}} \quad \text{(a working rule)}$$

or 1 ft candle = 1 c p for every 4π sq ft of area (at 100 per cent efficiency.)

EXAMPLES 17

1 How many 32 c p lamps will be required to give an illumination of 2 candle-feet over a working plane measuring 29 ft by 40 ft., if 65 per cent of the total emitted light falls on this plane ?

2. Two powerful street lamps of 1000 c p. and 800 c.p. (assumed uniform in all directions) are mounted 40 ft. above the road level and are spaced 80 ft. apart. Find the intensity of the horizontal illumination produced at a point on the ground midway between the lamp standards.

3 A single lamp of 100 c p. is suspended in an open space at a height of 20 ft. above the ground. Draw a curve showing as an ordinate the foot-candles of illumination produced along a line on the ground passing immediately beneath the lamp.

4 A rectangular space measuring 25 ft by 20 ft. is illuminated by lamps of 350 c p., one at each corner, and mounted 25 ft. above the ground Calculate the horizontal illumination on a plane 3 ft. above the ground at points (a) midway between the lamps on all sides, and (b) in the middle of the rectangle.

5. The following test figures were obtained with a photometer arranged to read the candle-power in a horizontal plane

passing through the centre of a lamp, itself capable of rotation about a vertical axis—

Angle of rotation	0	20	40	60	80	100	120	140	160	180	200
Candle-power	18	17	16	17	19	21 5	20	18	19	17	17
Angle	220	240	260	280	300	320	340				
Candle-power	16	16 5	17	19 5	21	20	19				

Determine the mean horizontal candle-power (M H C P)

6 The same lamp as in Ques 6 was tested for the candle-power in a vertical plane containing the lamp ; using Russell's method of the 10 selected directions, the following figures were obtained—

Angles above and below horizontal	5 7	17 5	30	44 4	64 2
Candle-power above horizontal	20	19 5	19	13	5
Candle-power below horizontal	21	19	18	16	9

Find the M S C.P and the spherical reduction factor.

7. The following test figures were obtained with an ordinary vacuum lamp, the candle-power being measured in a vertical plane at the given angles from the vertical, starting from the cap end—

Angle	0	15	30	45	60	75	90	105	120	135	150	165	180
C P	1	10	30	45	48	50	52	51	48	46	42	35	30

Find the M S C P. and the M H S C.P

8 An incandescent lamp giving a certain candle-power when run at a certain voltage has a filament diameter of 1 5 mils, and a length of 3 ft. Find the corresponding dimensions for a similar type lamp to give half the candle-power at double the voltage, the filament working at the same intrinsic brilliancy

9 A drawing office has to be well illuminated It is 100 ft. long by 40 ft. wide It has three rows of drawing tables, several tables, a head draughtsman's office, and a passage-way along one side Give sketches of an illumination scheme and some idea of the intensity and uniformity of the general illumination you would aim at. Show clearly any individual lighting you propose. (*A.M I.E E. April*, 1921.)

10 Find the illumination of the ground under the centre one of three lamps each of 25 c.p., arranged in a line 8 ft. apart and 15 ft above the ground. (*A M I E E., April*, 1923.)

11. Define the following terms (*a*) mean spherical candle

power, (*b*) lumen; (*c*) illumination, (*d*) brightness. What the illumination at the edge of a circular table 6 ft in diamet lit by one 100 c p lamp 4 ft above the centre?

(*A M I E.E*, *Oct*, 1923)

12. Calculate the cost of providing 100,000 lumen-hours lighting by means of the following illuminants—

(*a*) Candles each giving 1 c.p., costing 1d each and lastin 4 hours.

(*b*) 10 c p incandescent gas mantles, burning 0 6 cub ft pe hour, costing 5d each, and lasting 300 hours, with 60 per cen drop in efficiency

(*c*) Electric lamps giving 30 c p, one watt per candle-powe costing 2s. each and lasting 1000 hours, with 20 per cent dro in efficiency.

Cost of electricity, $4\frac{1}{2}$d per kWh Cost of gas, 4s. pe 1000 cub. ft.

13. A roadway to be illuminated by lamps on standarc 24 ft. high and spaced 120 ft. apart is to have a uniforml distributed horizontal illumination along the line joining th standards. Determine how the candle-power of the lamps mus be relatively distributed in a vertical plane in order to effec this, neglecting any illumination produced by a lamp beyon the mid-point between the standards.

14. A lamp of 250 c.p. gives uniform illumination in a directions, and is placed at a height of 12 ft. above the grounc Determine the horizontal illumination produced at points o the ground distant from the point vertically below the lam of 6 ft., 12 ft., and 18 ft.

15. Plan a scheme of lighting for a railway goods yard whic is 120 yd. by 600 yd., assuming that the mean illuminatio required is $\frac{1}{2}$ ft.-candle. Specify size, type, and height o proposed lamps.

16. (1) Name and define the units employed to specif (*a*) the illuminating value of a source of light, (*b*) the illumin ation of a surface upon which the light falls, (*c*) the tota luminous flux from the source

(2) A certain incandescent lamp has a mean spherica candle-power of 250. It is suspended at a height of 16 ft above the working plane, and is provided with a reflecto which gives an approximately uniform light distribution ove an area 16 ft. in diameter of the working plane below th lamp. Assuming that the efficiency of the reflector is suct that 45 per cent of the total light emitted by the lamp i directed on to this circular area, calculate the intensity o the illumination produced.

(3) About what value would you expect the illumination to have at the outer part of the same circular area if the reflector were removed from the lamp ? (*Whitworth*, 1924)

17 The filament of a 220 volt, 50 c p glow lamp has a diameter of 1 mil and a length of 4 ft. Calculate the diameter and length of filament required for a lamp of exactly similar type, but intended to be run on a 110 volt supply

Compare these two lamps as regards observable flicker on a 25 frequency circuit (*C. & G* , *Final*, 1926)

18 How would you determine the constants a and β in the expression candle-power $= aV^\beta$ for a glow lamp, where V is the lamp voltage ? Taking the value $\beta = 4\ 5$ for a tungsten filament vacuum lamp, determine the percentage variation of candle-power due to a voltage variation of $\pm$ 4 per cent from the normal value (*C & G.*, *Final*, 1927)

19 A matt white disc 1 ft. diameter is illuminated by a 400 c.p lamp the light of which falls normally on to the disc, the distance between the lamp and the disc being 10 ft. Regarding the illuminated disc as a distant source of light, calculate its candle-power in a direction making an angle of 45° with the line joining the disc and the lamp The disc may be assumed to be perfectly matt and to reflect 90 per cent of the light falling upon it (*Lond. Univ* , 1927, *El Tech.*)

18. Heating

1 calorie	4 2 joules	1 joule	0 24 calories
1 B Th.U	778 0 ft -lb	1 watt-hour	3 412 B Th.U.
1 gallon water .	10 0 lb	1 cub ft water	62 3 lb
1 lb.	453 6 grm		

EXAMPLES 18

1. The following figures for heat loss were obtained from experiments on steam-pipe covering by electrically heating the interior of a closed pipe—

Uncovered pipe 8·05 watts per sq. int of pipe surface per 1° F temperature difference.

Covered pipe : 3 22 watts per sq. int. of pipe surface per 1° F. temperature difference.

Apply these figures to find the heat loss from a closed water tank, given the following particulars—

Size of tank .	1 yd cube
Average temperature of hot water	130° F.
Average temperature of surrounding air .	50° F

If the water be electrically heated, the tank kept 90 per cen full, and the water used at the rate of 5 refills in 24 hours, th cold water entering at 50° F., calculate—

(a) The steady rate of heating required
(b) The efficiency of the uncovered tank arrangement.
(c) The efficiency of the covered tank arrangement.
Constants 1 metre = 3·28 ft Others as above.

(*A.M.I.E.E., Oct.*, 1922.)

2. A hot-water tank contains 120 gal. of water at 15° C the water temperature has to be raised to 65° C. by means o electrical resistance elements; the power available is 10 kW Determine the following—

(a) The time required to raise the temperature as above.
(b) The cost of heating if the energy costs ½d. per kilowatt hour. You may neglect radiation losses

(*A.M.I.E.E., Oct.*, 1924.)

3. A room measures 12 × 12 × 14 ft., and the air in it ha to be maintained at a temperature of 10° C. higher than tha of the incoming air; the ventilation has to be such that th air is renewed every 30 minutes. Neglecting radiation losses determine the capacity of an electric radiator suitable for th purpose. Density of air, 0·08 lb. per cubic foot, specific hea of air, 0·24 (*A.M.I.E.E., Oct.*, 1921.)

4. A cylinder contains 1000 grm. of oil, having a specific hea of 0·9, and contains a resistance coil of 8 ohms. The terminal of the resistance are connected to 100 volt supply mains. How long will it take for the oil to rise 50° C. in temperature assuming that the loss of heat is not more than 10 per cen of the whole heat produced, and that the heat capacity of th containing vessel (and coil) is equivalent to 200 grm. of water

(*C. & G., II*, 1919.)

5. An electric iron weighs 5 lb.; the loading is 600 watts Determine the initial rate of temperature rise in degree Centigrade per minute. State on what the final temperatur of the iron depends. Specific heat of iron – 0·16.

(*A.M.I.E.E., April*, 1926.)

6. A motor when started up was at the room temperatur of 15° C., and it was noticed that the current taken by th shunt field was 2 amperes. After a 6-hour run, this curren had fallen to 1·7 amperes, the applied volts remaining unaltered at 220. Find the final temperature of this field winding.

7. A coil of copper wire weighing 66 grm. is immersed in 2600 grm. of oil contained in a copper calorimeter weighing with the copper stirrer, 52·5 grm. A current maintained a

5 amperes is passed through the wire for 15 minutes, the p.d. averaging 10 volts, and a temperature rise of 10° C. was observed, loss of heat being prevented by lagging Find the specific heat of the oil. (Specific heat of copper 0 1)

8 A copper calorimeter weighing 200 grm. contains a litre of water at 15° C A coil of copper wire weighing 80 grm is inserted, and a current of 4 amperes passed through it Find the time required to bring the water to the boiling point, the mean p d. across the coil being 28 volts Neglect loss of heat by radiation, and take the specific heat of copper as 0 095

9 An electric furnace consuming 5 kW. takes 15 minutes to just melt 4 lb. of aluminium, the initial temperature being 15° C. Find the efficiency of the furnace, given specific heat of aluminium 212, melting point 658° C , and latent heat of fusion 76 8 calories per gramme.

10 Calculate the resistance required for a heater element to raise the temperature of 1 gal of water 50° C. in 5 minutes when working on a 220 volt supply. You may assume that all the heat is transferred to the water and no loss by radiation. What will be the cost per gallon of water heated when the energy is obtained at 2d per unit ? (Data as above.)

(*A.M.I.E E.*, 1921.)

11. A boiler to supply 100 lb. of steam per hour at 80 lb. per sq in absolute and 100° F of superheat is to be heated electrically from three-phase mains at 440 volts line pressure. If the temperature of the feed water is 130° F., calculate the line current for steady operation if the total heat of steam from 32° F under the above conditions is 1240 B Th U. per lb., the efficiency 93 per cent, and if the heating elements may be taken as non-inductive. (*Lond Univ* , 1926, *El. Tech.*)

12. An electric kettle had 600 c.c. of water placed in it, and was then switched on for a few minutes to give a temperature of just over 30° C. When the whole had cooled to 30° C exactly, a further 600 c c of water at 15° C. were added, and the resulting temperature was observed to be 23° C. Determine the water equivalent of the kettle.

13. In a further test on the above kettle, 1200 c c. of water were placed in it, and it was observed that the initial temperature was 15° C. On switching on a supply at 230 volts, it was observed that the mean loading was 2 5 amperes, and it was found that 14 5 minutes elapsed before the water just boiled. Find the overall and electrical efficiency of the kettle.

14. An electrically heated kettle holds 2 lb. of water and is to be used on a 220 volt circuit. It is required to raise the

temperature of the water from 55° F. to boiling point in minutes. Assuming an efficiency of 85 per cent, find (*a*) th resistance of the heating unit to be used, (*b*) the energy B. of T units required to boil the water (1 B Th.U = 2[illegible] calories, 1 calorie = 4 2 joules.) (*Whitworth*, 1927)

19. Heating of Machines and the Heating Time Constant

References *Journal I E E*, Vol 48, pp 214 and 735

Initial Rate of Rise of Temperature The machine at th start being at the temperature of its surroundings, the hea initially produced within it is all absorbed, i e the caloric equivalent to the watts lost during the first few minute equal the product of mass, specific heat, and temperatur rise of the machine parts during the same time Hence th initial rate of temperature rise may be ascertained. (Se Ques. 3)

Final Temperature Attained As the body warms up, hea is radiated or otherwise lost, the rate of loss depending upo the temperature, until at the final steady temperature hea is lost at the same rate as it is produced The temperatur will, therefore, be a logarithmic function of time, th equation being

$$\theta = \theta_f (1 - e^{-t/T})$$

where θ = temperature rise after time t (minutes or hours)
θ_f = final temperature *rise* attained, and
T = temperature time constant for the machine o part, being determined by the heat-absorbing and radiating properties and general cooling arrangements employed.

In practice, heat is produced at some internal point an has to be conveyed to the cooling surfaces, so that th "temperature" will depend somewhat upon how and wher measured, and in general the curve of temperature rise a practically determined is not truly logarithmic, and i certainly very doubtful at the origin. If, however, th cooling curve is determined, the whole mass is at a much more uniform temperature, and a better curve is obtained its equation being $\theta = \theta_f \cdot e^{-t/T}$.

Determination of Final Temperature Rise and Time Constant The exponential equations show that, after the elapse of a time T, the time constant, the body has a temperature rise of 63 2 per cent of θ_f, or, using the cooling curve, the machine will cool from any given temperature to one of 36 8 per cent of this in a time T. This latter curve is by far the best for the determination of the time constant When this is known, θ_f can be determined from the heating curve by knowledge of the fact that the temperature rise during time T is 63 2 per cent of θ_f

Both θ_f and T can be determined by selecting any two points on the heating curve and solving the simultaneous equations given by these two points (see Ques 5) The result depends upon the accuracy of the observed heating curve, but a good mean can be obtained from several pairs of points

Graphical Solutions (1) Plot the heating curve, draw the tangent to same at the origin, and draw another line through the origin having a slope 63 2 per cent of the tangent This line will cut the curve at an abscissae equal to the time constant T, and the ordinate through this point and intercepted by the tangent will give θ_f (see Fig. 2). The disadvantage of this method is that everything depends upon the tangent at the origin, where the curve is least reliable

(2) The following graphical method gives much better results in that it makes use of the truly logarithmic curve that most nearly fits the observed curve, and only the points well up the curve need be used, these being the most reliable

We have $\theta = \theta_f\,(1 - e^{-t/T})$,

whence $$\frac{d\theta}{dt} = \frac{\theta_f}{T}\,e^{-t/T} = \frac{\theta_f - \theta}{T}, \text{ since } e^{-t/T} = \frac{\theta_f - \theta}{\theta_f}$$

Thus $d\theta/dt$ is a straight-line function of θ, so that if this be determined at a number of points along the curve, and these values plotted against the θ's for which they have been determined, the straight line lying most evenly through these points can be used to determine θ_f and T as shown in Fig. 2.

$$\text{When } \theta = 0, \frac{d\theta}{dt} = \frac{\theta_f}{T}, \text{ whence } T = \frac{\theta_f}{\left(\frac{d\theta}{dt}\right)_{\theta=0}} = \tan\beta$$

This method is applicable to short heat runs The temperature is run up rapidly by overloading, and then normal loading is restored After the lapse of a few minutes, readings are commenced of time and temperature, and plotted as shown in Fig. 2*a* The $\theta - d\theta/dt$ line is plotted for this portion of the curve, and it will intersect the ordinate axis at θ_f, and T will still be tan β.

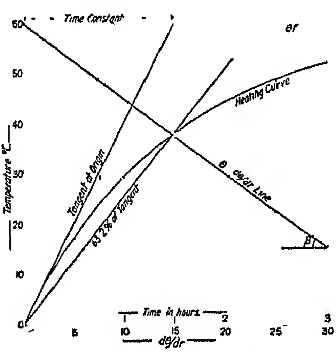

FIG 2 HEATING OF MACHINES

Overload Capacity Case 1 Heat produced by copper loss only (Ques 2) Let k be the fractional increase of load, i e $k = 1\ 5$ for 50 per cent overload. Heat is now being produced k^2 times as fast as before, and the initial temperature rise is k^2 times the original rate for full-load heating But rate of initial rise $= \theta_f/T$, so that, if the new loading is continuous, the new θ_f attained will be k^2 times the previous value, i.e $\theta = k^2\theta_f(1 - e^{-t/T})$, from which either θ, k, or t can be ascertained if the other two are given

Case 2. Heat being produced by both copper and iron and friction losses, assume the latter to be constant, and that at normal full-load the variable copper loss equals this constant loss. On overload, the total heat will be $(k^2 + 1)/2$ of its value at normal full-load, and it loading is continuous, we have

$$\theta = \frac{k^2 + 1}{2} \theta_f (1 - e^{-t/T}),$$

to be used as above (see Ques. 6 below).

EXAMPLES 19

1. Discuss the question of estimating the final temperature rise of electrical machinery by means of "short heat" runs, and show how the estimation of the final temperature rise is made Of what value is a knowledge of the heating time constant of a piece of electrical apparatus?

(*A M I E E.*, *Oct*, 1924)

2 Describe a method of estimating the "time constant" of a field coil. The field coil of a certain machine has a time constant of 30 minutes, and the final temperature rise is 40° C. Calculate the overload this coil will stand if the temperature rise is not to exceed 50° C. at the end of one hour.

(*A M I.E E.*, *Oct.*, 1924.)

3 Explain how to estimate the rate of rise of temperature in the various parts of a D C. machine The field coils on a machine are excited with 2·5 amperes at 230 volts, and the weight of copper in the coils is 60 kg Estimate the rate at which temperature will begin to rise when the coils are excited from the cold condition (Specific heat of copper 0·1.)

4 A machine is run on load and the mean temperature rises are as follows—

Time of run in hours	0·25	0·5	1·0	1·5	2·0	2·5	3·0
Temp rise, deg C	10	18	27	35	42	48	50

Estimate, by any graphical method, the final temperature rise of the machine and the probable value of the "heating" time constant If the final temperature rise had been 40° C, what would have been the temperature rise at the end of a run of one hour? (*A M I.E E*, *Oct.*, 1925)

5 A machine run on steady full-load showed the following temperature rises at the end of the specified time intervals—

Time in hours	0·25	0·5	1·0	1·5	2·0	2·5	3·0
Temp rise, °C	9·5	17·0	29·2	38·0	44·2	48·7	52·0

Estimate the final temperature rise under the same conditions of loading. It, under the same cooling conditions, the machine were to be so loaded that the final temperature rise should not exceed 45° C, what temperature rise would be obtained at the end of one hour at this loading, starting from the cold?

6 According to what law does the temperature of a motor increase when started and run with constant losses?

A certain motor has a temperature rise of 50° C when working continuously at full load. It is found that the armature winding shows a rise of 25° C one hour after being started cold under full load. Find (i) the time which would be taken theoretically for the winding to reach a temperature of 50° C if there were no loss of heat by convection, etc., and (ii) the actual time which the motor could be allowed to work under an overload of 50 per cent without exceeding the maximum allowable temperature of 50° C., assuming the motor to be started cold

(*Whitworth*, 1926)

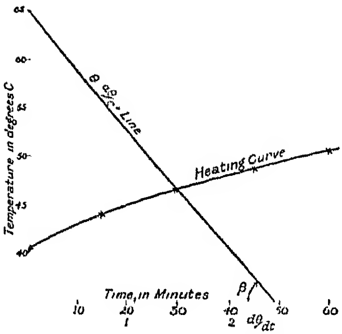

FIG 2*a* SHORT HEAT-RUN TEST OF MACHINES

7 The following readings give the heating curve for a machine run on steady load—

Time in hours	0·25	0·5	1·0	1·5	2·0	2·5	3·0
Temp rise, °C	7·65	14·1	25·6	34·2	41·1	46·1	50·5

Find graphically the heating time constant and final temperature rise, and check your values by calculation Specify also the maximum rise permissible for a one-hour run if the final temperature rise is not to exceed 55° C. under the same cooling conditions.

8. The following figures were obtained on a short heat run—

Time in minutes	0	15	30	45	60	75
Temp. rise, °C	41	43·8	46·4	48·6	50·5	52·2

Estimate by a graphical method the time constant and final temperature rise. (See Fig. 2*a*.)

20. Swinburne Test for D.C. Shunt Machines

Test (a). Machine run light as a motor at normal voltage and speed. Input gives constant no-load losses, i.e. friction, windage, iron and (unless separately measured) the field loss

Test (b). D. C. current passed through stationary armature

and p d noted Hence find resistance of armature, r_a Copper loss for any loading is given by armature current squared times r_a

Efficiency at given loading obtained from

output/output + losses (*a*) and (*b*) above.

EXAMPLES 20

1 A generator having a full-load output of 100 kW at 460 volts gave the following test figures—

(*a*) Running light as a motor at 460 volts, total current taken was 9 8 amperes.

(*b*) A current of 40 amperes passed through the armature gave a p d. of 4 6 volts across the armature terminals

Calculate the efficiency when running at $\frac{1}{2}$, $\frac{3}{4}$, 1 and $1\frac{1}{4}$ times full-load At what load is the efficiency a maximum?

2 A 20 b h.p. motor for 200 volts was tested by the Swinburne method with the following results. running light, it took a current of 6 5 amperes through the armature and 2 2 amperes through the field. At standstill, a p.d. of 3 volts applied to the armature brushes causes a current of 70 amperes to flow through the armature Calculate the efficiency on full-load

3. Plot the efficiency curve of a 500 volt 80 b.h.p. motor which when tested at no-load gave the following results—

(*a*) Input 6 amperes, running light at normal speed and voltage

(*b*) Armature resistance (hot) 0·2 ohm.

Criticize this method of deducing the full-load efficiency and suggest methods of increasing its accuracy

(*A.M I E E*, *April*, 1921)

4. A 230 volt 10 b.h p D.C. motor on a "Swinburne" test was separately excited and the following figures obtained—

(*a*) Field excitation : 230 volts, 1 25 amperes.

(*b*) Armature running light at full speed · 227 5 volts, 3 4 amperes

(*c*) Armature at rest · 5 volts produced a current of 80 amperes.

Estimate the full-load efficiency of the motor

If the efficiency of the motor had been obtained by means of a brake test, what would have been its probable value, and why would it differ from the value obtained from the no-load test? (*A M.I E.E.*, *Oct*, 1925)

5. The efficiency of a direct-current motor obtained by the summation of the no-load losses and the armature circuit I^2R

losses is 90 per cent. When tested on a brake the efficiency is found to be only 89 per cent Give a full explanation of the reason for the difference (A M.I.E E., Oct, 1923)

6. A 220 volt shunt motor running light takes 4 amperes. The field resistance is 220 ohms and the resistance of the armature (hot) is 5 ohms What will be the armature current when the motor is giving 6 h.p ? Explain what assumptions are made in calculating this result, and what errors these assumptions are likely to involve.

(*Lond Univ., El Tech.*, 1922)

7. A shunt motor running light on a circuit at 180 volts takes 2·5 amperes The resistance of its field windings is 800 ohms, the armature resistance is 0 6 ohm, and brush drop 1 volt.

What will be the efficiency of the motor when giving an output of 25 b h p, the brush drop now being 2 volts ?

(*Whitworth*, 1926.)

21. Brake Tests on Motors

In the Soames or Proney Brake tests, an effective weight or force acts at a definite leverage upon a brake pulley driven by the motor

If d = diameter of brake pulley (including rope thickness for rope brake) in feet,

W = effective weight acting at the rim of the brake pulley, in lb.

N = revolutions per minute of motor,

then $W \times d/2$ = torque on motor in lb.-ft.,

$W \times d/2 \times 2\pi N$ = work done in ft.-lb. per minute,

$$\frac{W \times d/2 \times 2\pi N}{33{,}000} = \text{brake horse-power.}$$

If V = volts p d applied to motor } *D.C.*

I = total current taken by motor }

then VI = watts input.

$$\text{Efficiency} = \frac{\text{watts output}}{\text{watts input}} = \frac{Wd\pi N}{VI} \times \frac{746}{33{,}000}$$

EXAMPLES 21

1. In a Proney Brake test on a 440 volt D.C. motor, the brake arm is held at its extremity by a spring balance, the

point of application being 2 ft. 6 in. from pulley centre When a pull of 20 lb was observed on the balance, the motor was taking 25 amperes at 440 volts, and the speed was 1400 r p m Calculate the b h.p. and the efficiency

2 A D C. motor tested with a Soames Brake on a pulley of 15 in diameter showed an effective pull of 15 lb when the speed was 1000 r p m , and the input was 6 5 amperes at 230 volts. Find the efficiency.

3 The following test figures were obtained on a 4-pole D.C. shunt motor . brake load 18 lb. at a leverage of 18 in , input, 200 volts, 32 6 amperes at a speed of 440 r.p.m. Find the efficiency.

4. The following test figures were obtained on a shunt motor fitted with a Soames Brake having the weights at a distance of 18 in. from the pulley centre, the voltage being maintained constant at 230—

Weight balanced lb	Current input Amps	Speed r p m	Horse-power b h p	Efficiency per cent
2	3 8	1540		
4	7 3	1530		
6	10 4	1520		
8	13 1	1510		
10	16 7	1500		

Calculate the b h p and efficiency in each case

22. Running Down Tests and Field's Test

Kinetic energy $= \frac{1}{2}I\omega^2$

Energy loss $W = I\omega d\omega/dt$ watts.

where I = moment of inertia of the moving parts, in kg metres^2,

ω = angular velocity $= 2\pi n$,

n = r.p. second = r.p.m./60,

$d\omega/dt$ = angular acceleration.

Method of Test Readings are obtained of r p.m at various intervals of time as the machine slows down, under various conditions, such as with field excited, then unexcited, and also when the armature is supplying a load, or the machine is otherwise loaded to a known extent. Curves are plotted

of r p m against time, all of which should extend above and below normal speed At normal speed, the value of $d\omega/dt$ is found, and I can be eliminated from the loaded test, whence the losses due to the various causes can be calculated (see first example below)

EXAMPLES 22

1 The following test figures were obtained on a D C. shunt motor—

Field unexcited	R P M	1140	1000	850
	Time (sec)	0	3 5	7 9
Field excited	R P M	1140	1000	850
	Time (sec)	0	2 0	4 45
Armature loaded	R P M	1140	1000	850
	Time (sec)	0	1 5	3 1

The field was separately excited at normal value in second and third tests, and in the latter test a current of 1 8 amperes at 178 volts was flowing at the moment the machine passed through normal speed. Find the iron and friction losses, and the moment of inertia and energy of rotation at the normal speed of 1000 r p m.

2 Describe a modern stroboscopic method of observing the speeds of machines on the running down test, showing how the disc is illuminated. Compare this in accuracy and convenience with an electrical method of making the same test.

A machine is estimated from its performance to have a loss of 150 kW. at a speed of 1200 r p.m. On the retardation test it is observed to lose 50 revolutions every minute at this speed. Find the moment of inertia of the moving system, and calculate the energy of rotation at the above speed.

(*Lond. Univ.*, 1924, *El. Mach.*)

3 Describe how, from retardation tests and a knowledge of the machine dimensions, the core loss of a large turbo-alternator may be estimated. A 2000 kW. turbo-alternator operates at 1200 r p m. on a 40 period, 5750 volt line. The calculated kinetic energy of the complete machine is 7900 ft.-tons, and when (*a*) unexcited, the speed falls 2 revolutions per second in 49 seconds, and (*b*) excited, the speed falls 2 revolutions per second in 29 seconds. Estimate the core loss.

(*A.M.I.E.E.*, *Oct.*, 1924.)

4 A large rotary converter tested for running down showed a fall in speed from 1500 r.p.m. to 1450 r.p.m. in 40 seconds when unexcited, and in 25 seconds with the field at normal

excitation With a load of 1 kW being supplied by the armature, the corresponding time for the retardation was 20 seconds Estimate the core loss due to the excitation, and the moment of inertia of the rotating mass at 1500 r p m.

5 A test on two coupled similar tramway motors, with their fields connected in series, gave the following results when one machine acted as a motor and the other as a generator. Motor. armature current, 56 amperes, voltage, 550 volts; voltage drop across field winding, 40 volts Generator. armature current, 44 amperes, armature voltage, 400 volts, field voltage drop, 41 volts Resistance of each armature, 0 3 ohm Calculate the efficiency of motor and gearing at this load and criticize the method of testing (*A M I E E., April*, 1927)

23. D.C. Instruments

References *Industrial Electrical Measuring Instruments*, by K Edgcumbe (Constable) *Electrical Measuring Instru-Meters*, by Gerhardi (Benn Bros) *Journal, I.E E*, Vol 65 (1927), page 553

EXAMPLES 23

1. Describe the action and construction of an instrument suitable for measuring flux (*A M I.E E*, *April*, 1922)

2. Sketch and describe the main design and constructional features of a "megger set"

Explain the theory of the working of the ohm-meter (*A M.I E.E*, *April*, 1925)

3 Describe, with connection diagrams, the construction of any form of integrating wattmeter suitable for use with three-wire c c systems of supply, and indicate how you would give it a rating test without using the full power recorded during the test.

4. Describe the essential features of a ballistic galvanometer, and establish a formula for the quantity of electricity passed in terms of the swing and constants of the instrument What do you understand by "damping"?—explain why it is desirable to keep it down to a minimum, and how this may be effected. From the quantity expression, obtain the conditions that must exist for the movement to become just aperiodic, and show that the quantity sensibility is reduced to 36 8 per cent of that appertaining when the movement is on open circuit

5. Sketch a good form of moving coil voltmeter Estimate the deflecting torque produced by a coil of 150 turns with a side of 4 cm. and a width of 2 cm. (mean values) when carrying

a current of 20 milli-amperes and situated in a uniform radial field of density 500 lines per sq cm

6. Sketch the movement of one form of each of the following types of voltmeter (*a*) moving iron, (*b*) moving coil

Explain clearly the action of the deflecting couple and of the controlling device which acts in opposition to it, and give fully the reason why the scale of one of the instruments can be made with equal divisions, while that of the other cannot

(*Whitworth*, 1925)

7 By means of hand sketches show the construction of some modern form of "precision" measuring instrument Point out the special design features of the instrument described, and indicate the processes involved in its manufacture and calibration. (*A M I E E* , *Oct* , 1925)

8 A milli-voltmeter is scaled 0 to 150. Its resistance with its connecting leads is 1 ohm, and it gives full-scale deflection with 0 075 volt Make an approximate design of a 1500 ampere shunt suitable for this instrument

(The specific resistance of a suitable material for making the shunt leaves is 49×10^{-6} ohm per cm./cm ^{2})

(*A M I E.E* , *April*, 1925)

24. Tractive Efforts of Motors and Line Currents

1 h p = 33,000 ft -lb per minute = 550 ft -lb per second = 746 watts

Force required to move load W up an inclined plane of inclination θ to the horizontal is $W \sin \theta$ (friction neglected).

To accelerate a body, force = mass × acceleration.

EXAMPLES 24

1. The motor on an electric crane works with an efficiency of 86 per cent when raising a 2-ton load a distance of 80 ft. in 20 seconds through the intermediary of winding gear having an efficiency of 62 per cent. Find (*a*) the b.h.p. of the motor, and (*b*) the current drawn from the 250 volt supply.

2. Two geared motors in parallel on a 550 volt supply drive a 20-ton car at 20 m.p.h The resistance to traction is 30 lb. per ton, the efficiency of the gearing is 80 per cent, and the resistance drop on each motor is 5 per cent of terminal p d. Find the current taken from the line.

3 A 15-ton car is taken up an incline of 1 in 25 at a speed of 12 m.p.h., the resistance to traction being 12 lb. per ton,

and the overall efficiency from motor to wheels is 55 per cent Find the line current at 600 volts.

4 A train of weight 200 tons is hauled up an incline of 1 in 30 by an electric locomotive weighing 70 tons, having an overall efficiency of 60 per cent. The resistance to traction is 28 lb. per ton, and the steady speed obtained on the incline is 5 m p h The supply is at 1200 volts Find the current drawn from the line

5 A train weighing 250 tons in all starts from rest on a 1 per cent incline The frictional resistance is 12 lb per ton, and the overall efficiency is 80 per cent Assuming that the induction factor of the motors remains constant and that the uniform acceleration is 4 ft. per second per second, find the current taken from the 550 volt lines at the instant the train reaches a speed of 8 m p h.

6 A pump is required to lift 60,000 gal of water per hour through a height of 100 ft. Allowing 12 ft of head for pipe friction and pump efficiency 70 per cent, what current would be taken by a direct-current motor running on a 500 volt supply when driving the pump at the above duty? Give the h.p of the motor you would install, and assume a reasonable efficiency (*A.M I.E.E.*, *April*, 1921.)

7 An output of 480 tons of material per shift is required by endless-rope haulage from a dip 1000 yd long, gradient 1 in 8, weight of empty tub 5 cwt., weight of loaded tub 20 cwt Assuming 6 working hours per shift and a haulage speed of 3 miles per hour, and that the motor is required to exert a constant pull of 1200 lb. on the rope to overcome all friction losses, calculate the horse-power of the motor, assuming an efficiency of 75 per cent (*A M I E E*, *Oct*, 1922.)

8 Calculate the power taken by an electrically driven feed pump which has to deliver 50,000 lb. of water per hour to a boiler working at 275 lb gauge pressure Estimate the motor and pump efficiency, and allow 65 ft head to cover losses in pipe line between pump and boiler, 1 lb. per sq in. being taken = 2 31 ft. of water (*A M.I E E.*, *April*, 1923.)

9 Give an account of an electrically driven multistage turbine pump such as would be installed to discharge 550 gal per minute against a maximum head of 600 ft., stating the following: (*a*) the water horse-power; (*b*) a reasonable pump efficiency; (*c*) a reasonable motor efficiency Calculate from this the electrical units used per ton of water pumped. (1000 h.p.-hours = 746 electrical units.)

(*A.M.I.E E*, *Oct.*, 1923.)

10 What current would be drawn from a 440 volt D C. power circuit by a motor coupled to a gear-driven pump which requires a torque of 200 lb -ft at 150 r p m , assuming reasonable efficiencies for the motor and gear ?

(*A M I.E.E* , *April*, 1921)

25. D.C. Armature Windings and Slot Design

References *The Dynamo*, by Hawkins (Sir Isaac Pitman & Sons, Ltd) *Continuous Current Machines*, by S P Smith (Benn Bros) *Insulation and Design of Electrical Windings*, by Fleming and Johnson (Longmans, Green & Co)

Symbols p = pairs of poles , a = pairs of armature paths , Z = number of conductors

Lap Windings Winding advances at back of armature by a forward step y_1 equal generally to a pole pitch, and returns at front of armature by a back step y_2 to the conductor 2 in advance of the starting conductor, i e $y_1 = Z - 2p = y_2 + 2$, provided both y_1 and y_2 are odd

Short Chord Windings are obtained by reducing both pitches so that the advance for y_1 is something intermediate between a pole pitch and a pole arc

Commutator connections are made in the back step y_2, the number being an even sub-multiple of the number of conductors, and such that a commutator of about three-quarters the diameter of the armature is obtained with a segment pitch of about 2 in or 5 mm (minimum)

Armature Paths and Brushes There will be as many paths as poles, and the same number of brushes *must* be provided, i e $p/a = 1$

EXAMPLE

4-pole lap winding with 248 conductors. 248 − 4 = 62

Pitches, $y_1 = 63$, $y_2 = 61$, or

$y_1 = 61$, $y_2 = 59$ will give shorter end connections

```
Winding table · 1   3   5   7   9
                \ / \ / \ / \ / \
                 62  64  66  68  70 for latter case
```

Commutator segments · 124 would give a connection in every back step, while 62 gives a connection each alternate back step.

Wave Windings Here the winding steps are always forward, so that a conductor is taken under each pole in succession, and $y_1 = y_2$ This imposes a restriction on the number of conductors employed, since once round the armature, i e $2py_1$, must come to a conductor ahead of or behind (better) the starting conductor, i e

$$1 + 2py_1 = Z + 3, \text{ or } Z - 1, \text{ whence } 2py_1 = Z \pm 2$$

Commutator connections as for lap windings, in the y_2 step, which is now, however, obviously a forward step

Armature Paths and Brushes There will only be two armature paths, i e $a = 1$, and there need only be two sets of brushes, a pole-pitch apart, but the additional sets *may* be added at the other pole pitches, to facilitate the entry of current to the armature

EXAMPLE

A 6-pole wave winding with about 250 conductors.

Z can be either 244 or 248, since $Z \pm 2 = 246 = 2\ 3\ 41$, giving thus a pitch of 41

```
Winding table for Z = 244     1   83     165    3
                               \ / \    /   \  /\
                               42   124      206 44

          for Z = 248 :       1   83     165    247   81
                               \ / \    /   \   /  \  /
                               42   124      206    40
```

The former winding involves a cross-over of the end connection from 206 to 3 over that of 1 to 42, which is avoided in the second arrangement It is thus generally better to choose Z given by the minus sign in the above equation, i e the larger of the two possible values.

Duplex Windings. Two ordinary windings interlaced but independent, connections being made with alternate commutator segments in either winding, instead of with contiguous segments Thus the number of segments and conductors is doubled The two windings are put in parallel by the brushes bridging more than one segment The voltage is thus that of an individual winding, but the pairs of parallel armature paths have been doubled.

Triplex Windings Three ordinary windings interlaced but independent, necessitating three sets of commutator

segments, each winding being connected to every third segment The windings are paralleled by the brushes bridging at least three segments The voltage is as for a single winding, but the number of parallel armature paths is increased threefold

Doubly Re-entrant Windings In the duplex winding, remove one commutator segment and a set of conductors connected thereto. On completing the first winding, the beginning of the second winding will be automatically picked up on the segment next in advance of the beginning one of the first winding, and the second winding will finish at the segment where the first started, thus giving a self-closed winding Otherwise the winding is exactly similar to the duplex winding

Trebly Re-entrant Winding In the triplex winding, if one commutator segment and one set of conductors associated with it are removed, then the three windings will follow on one another and ultimately close at the first commutator segment, thus giving one self-closed winding Otherwise this winding is similar to the triplex

Slot Design Odd number conductors, i e those passing from front to back, are put in the top of the slot, while the even number conductors passing from back to front, are placed in the bottom of the slot. Maximum p d. will occur between top and bottom conductors, necessitating ample insulation between the layers as well as against the walls of the slot, but conductors in one layer only require to be lightly insulated from one another

EXAMPLES 25

1 Set out winding tables for both lap and wave windings for an 8-pole machine with 186 conductors.

2 A 4-pole, direct-current armature has 31 slots and 93 commutator bars. The winding is of the two-circuit wave type and consists of 93 turns of copper strap. Sketch one turn of the winding, showing the commutator pitch, the slot pitch, and the positions in the respective slots of the two sides of the turn (*A M I E.E.*, *Oct.*, 1923.)

3. A shunt-wound D C generator of 200 kW. output at 500 volts, has 6 poles and runs at a speed of 400 r p.m. The diameter and the length of the armature are as follows:

diameter, 33 5 in ; the length 9 75 in If the total flux in the air-gap is 5 2 $\times$ 10^6 lines, estimate (*a*) the number of armature conductors, (*b*) the number and dimensions of the armature slots Give also a sketch showing the arrangement of the conductors in the slots. State the type of winding proposed and the winding pitches to be used.

(*A.M I E E*, *April*, 1924)

4. The armature of a 4-pole 460 volt motor is 13 25 in diameter, and the number of armature conductors is approximately 660. Design a wave winding suitable for this motor, showing the arrangement of the conductors in the slots and the first few steps in the winding, with the commutator connections (*A M I E E*, *April*, 1925.)

5 Make a winding table for an armature winding for a D C. motor to run at a speed of 750 r.p.m when connected to a 500 volt circuit. The field magnet has 4 poles, each large enough to carry a flux of 4 3 megalines The armature punching has 39 slots Only three lines of the winding table need be written out (*Lond Univ.*, 1922, *El Mach*)

6. A 250 volt 200 kW direct-current generator is required, the speed at full load being 400 r p m There is available a 6-pole magnet frame with an unwound armature 42 in in diameter and having 72 slots The normal flux per pole being about 5 $\times$ 10^6 lines, find what armature winding could be used for the above purpose, giving details of the windings and stating the number of commutator segments required Point out any difficulties likely to be experienced with the arrangements suggested (*Lond. Univ.*, 1924, *El Mach.*)

7 When designing a direct-current generator, two trial designs *A* and *B* were made. For *A* the specific magnetic loading factor was 40,000 lines per sq in, and the specific electric loading factor was 750 ampere conductors per inch of periphery. For *B* the loading factors were 50,000 and 600 respectively. The armatures for *A* and *B* were designed with wave windings having the same number and size of slots and the length and depth of the armature cores were the same. The space factors in the slots were 0 70 for *A* and 0 75 for *B*.

Calculate the ratio of the resistance loss in the armature winding of *A* to that in *B*. Which armature will have the larger iron losses ? (*Lond. Univ*, 1925, *El. Mach.*)

8. An 8-pole direct-current generator gives 1000 kW. at 500 volts. Assuming a value for the current density, proceed to design completely the armature slot when there are six

conductors per slot, showing all details and dimensions in freehand sketch.

How would you determine the length of a turn in th windings? (*A M I.E.E*, *April*, 1922)

26. D.C. Generators—Voltage Formula

$$E = \Phi Zn\,(p/a)10^{-8} \text{ volts}$$

where Φ = total flux per pole entering armature,

Z = total armature conductors in winding,

n = speed in r p sec = r p m /60,

p = pairs of poles,

a = pairs of parallel paths through the armatur winding,

Note —For a simple *lap* winding, $p/a = 1$ For a simpl *wave* winding, $a = 1$

EXAMPLES 26

1 An 8-pole dynamo running at 1200 r p.m and with a excitation of 2 5 megalines per pole generates 440 volts. Fin the necessary number of conductors if the winding is (*a*) wave and (*b*) lap

*2 A generator delivers 40 kW at 200 volts Its armatur is a 4-pole wave winding having a resistance of 01 ohm, an consists of 151 turns, and the flux per pole is 2 megalines Find the speed.

3. A 4-pole lap wound generator with 1200 conductor generates 250 volts on open circuit when driven at 500 r.p m. The pole shoes have a bore of 14 in and the ratio pole arc/pol pitch is 0 7, while the length of the shoes is 8 in. Find the mear flux density in the air-gap.

4 Develop a formula by which the E M.F. generated by a direct-current machine may be estimated Extend the formula to show how it may be used to calculate the E.M F. which would exist between any two of the slip rings if the armature were tapped at three equidistant points.

(*A M.I E E.*, *April*, 1925)

5. An 8-pole generator has an output of 30 kW at 250 volts when driven at 300 r p m. The armature is lap wound with 1500 conductors and has a resistance of 0·1 ohm. The field cores are 8 in. diameter and the leakage coefficient is 1 2. Calculate the flux density in the field cores.

6. A 12-pole d c generator has an armature according to the following specification—

Slots 120, with 4 conductors per slot, each capable of carrying 250 amperes, winding lap

If the pole flux is 5 megalines, at what speed must the machine be driven to produce a voltage of 240 on open circuit? If the voltage drops to 230 on full-load, what would be the rated output of the machine?

27. D.C. Motors

If V = voltage of supply lines,

E = back E M F generated $= \Phi Zn\,(p/a)\,10^{-8}$ volts,

I_a = armature current,

r_a = armature resistance,

Then $V = E + I_a r_a$

Power $W = VI_a = EI_a + I^2_a r_a$

= mechanical power P + copper heat

If T = torque in lb -ft ,

n = r p sec = r p m /60

Then $P = 2\pi nT$ ft -lb. per sec

$$= 2\pi nT\,\frac{746}{550}\text{ watts} = 8\ 52nT \text{ watts} = \text{also } EI_a,$$

Whence $T = EI_a/8\ 52n = 0\ 1174MI_a$ lb -ft

Where $M = E/n = \Phi Z\,(p/a)\,10^{-8}$ = *induction factor.*

EXAMPLES 27

1 The following figures refer to the design of a traction motor: winding 4-pole lap with 400 conductors, pole shoe 8 in. long, subtending an angle of 60° at the centre, the bore being 1 ft. in diameter, flux density in air-gap is 7000 lines per sq cm. Calculate the torque developed when the armature takes 25 amperes.

2 The armature of a 4-pole motor has 280 conductors arranged in a 4-circuit winding The field poles produce a flux of 2 5 megalines. Find (*a*) what torque will be developed when the armature takes 75 amperes, and (*b*) the pull on the belt (losses neglected) if the pulley has a diameter of 18 in.

3. Calculate the b.h.p. of a motor having the following data: overall efficiency, 83·5 per cent; speed, 550 r p m., when

taking 65 amperes, armature resistance, 0 2 ohm, flux p pole, 2·5 megalines, armature winding lap with 12 conductors

✓ 4 A 4-pole series motor develops 20 b h p when runni on a 230 volt supply, at an efficiency of 84 per cent. T armature carries 1080 conductors lap wound, having a resi ance between brushes of 0 12 ohm, while the field winding has resistance of 0 1 ohm The magnetization curve is as follows

Amperes	10	20	30	40	50	60	70	80	9
Megalines per pole	6	1 04	1 38	1 67	1 9	2 08	2 25	2 39	2

With current values as abscissae, plot curves showing the tot mechanical torque, total horse-power, and speed.

5 A 440 volt 10 b h p. shunt motor runs unloaded at 15 r p m The resistance of the armature circuit is 1 ohm, a the full-load efficiency is 75 per cent. Draw a speed-lo curve, assuming the field to maintain constant excitation, i resistance being 169 ohms

6 Find the rise in speed of a shunt motor at the end of 6-hour run on full-load if it starts at 1500 r.p m and t temperature of the machine as a whole rises 35° C. Assun the saturation (or magnetization) curve to be straight over t range concerned, and the line voltage constant. Temperatu coefficient of copper is 004 per degree C.

7 It is desired to reduce the speed of a 460 volt 10 b h shunt motor by 25 per cent by the insertion of resistance the armature circuit The torque is to remain unchanged, ar the efficiency is 85 per cent Calculate the necessary resistanc given field current constant at 1 1 amperes and armatu resistance 0 2 ohm

8. When a shunt generator is run at 1400 r.p m and 25 volts, it has an output of 50 kW. The resistances of armatu and field circuits are 0 12 and 40 ohms respectively At wh speed will it run as a shunt motor at the same voltage an taking 50 kW. from the line ?

9 A traction motor is found to run at 570 r.p m. at a certa current and at 600 volts. Determine the car speed at th current, both at 550 volts and at 275 volts, the gear reductio being 62/21, the wheels 36 in. in diameter at the tread and th resistance drop in the motor 30 volts What gears would b required to give a speed of approximately 23 m.p.h with th motor at the same current and at 550 volts ?

(*A.M.I.E.E., Oct.*, 1924.)

10. Calculate the total current taken by the following shunt-wound D C motor . output, 10 b h p , 220 volts , total iron losses, 670 watts , windage and friction losses, 100 watts ; resistance of armature, 0 4 ohm ; brush contact resistance drop (total), 2 volts , resistance of shunt field winding, 110 ohms

If the speed of the motor is now doubled by means of a resistance in the field circuit, calculate the current taken at the new speed (*a*) if the torque is unchanged, (*b*) if the horse-power output is unchanged

Assume that the total iron losses vary as the square of the flux density, that the friction and windage losses vary directly as the speed, and that the ratio of the field ampere-turns at the two speeds is as 3 to 1 (*Lond Univ* , 1921, *El Mach*)

11 Calculate the torque in lb -ft. exerted by a 4-pole lap-wound motor when it is taking an armature current of 64 5 amperes. The armature has 588 conductors , the pole-shoes subtend an angle of 60°, and are 7 in long The bore is 10 in diameter and the field coils produce a flux density in the gap of 8000 lines per sq cm

12 A 4-pole series-wound 220 volt direct-current fan motor runs at 650 r.p m with the field coils in series, taking a current of 23 amperes Estimate the speed and current when the field coils are arranged with two pairs of two in series, in parallel, assuming that the torque required to drive the fan increases as the square of the speed Point out what approximations are made, and indicate in what direction the answer is likely to be incorrect (*Lond. Univ.*, 1923, *El Tech.*)

13. Sketch the forms of the " mechanical characteristic " for shunt and series D.C. motors, and estimate the percentage change in speed from no-load to full-load of a shunt motor having the following data: b.h.p., 25 , full-load efficiency, 85 per cent ; volts 230, constant ; armature resistance, 0 1 ohm , field resistance, 70 ohms.

14. A 4-pole series motor has a magnetization characteristic given by the following figures—

Amps through field magnet .	10	20	30	40	50	60	70	80	90
Flux per pole (mega-lines) .	0 29	0 55	0 74	0 85	0 92	0 97	1 01	1 06	1 08

If the armature has 820 conductors and is wave wound, and the resistance of the armature and field magnet windings is

0 15 ohm, estimate the speed at which the motor will run when supplied from a constant p d. of 230 volts, when taking a current of (*a*) 45 amperes, (*b*) 85 amperes. Calculate also the torque in lb -ft. which the motor will exert when carrying these currents (*Lond. Univ* , 1924, *El Tech*)

15 A fan driven by a shunt motor off a 200 volt supply takes 50 amperes when the speed of the fan is 1000 r p m., the mechanical power given to the fan being 9·5 kW The torque required by the fan varies as the square of the speed It is desired to bring the speed down to 850 r p m. by the insertion of a resistance in the armature circuit. Determine the value of this resistance and the power lost in it. (Frictional losses and armature reaction may be neglected)

(*Lond. Univ* , 1924, *Power*)

✓ 16 A shunt-wound motor runs at 500 r.p m on a 200 volt circuit. Its armature resistance is 0 5 ohm and the current taken is 30 amperes in addition to the field current. What resistance must be placed in series with the armature in order that the speed may be reduced to 300 r p m., the current in the armature remaining the same ? If the load is changed so that with the inserted resistance the armature current is reduced to 15 amperes, what will then be the speed ?

(*Lond Univ* , 1925, *El. Tech.*)

17 A 440 volt shunt motor runs at 1600 r p.m. on no-load.

(1) Calculate its speed when developing 10 b.h.p , assuming that its field current remains constant at 2 amperes.

Armature resistance 0 8 ohm, total brush contact drop 2·1 volt. Efficiency of motor at given load = 82 per cent.

(2) By what percentage must the field be weakened to bring the speed up to its no-load value ? (*Whitworth*, 1924.)

18 Explain in a few words why the torque of a motor depends upon the speed at which it runs.

Give an outline of the successive stages in the connections effected by a tramway controller of the ordinary series-parallel type in starting a tram-car.

Indicate in a diagram on squared paper the variation in the following quantities as the controller handle is moved into successive stops, assuming a practically uniform rate of increase of speed to be maintained—

(*a*) Current taken from the line.
(*b*) Torque exerted by both motors together.
(*c*) Power developed by both motors together.
(*d*) Power taken from the line.
(*e*) Speed of the car. (*Whitworth*, 1926)

19 A certain type of motor for driving a recording mechanism has an armature consisting of a horizontal aluminium disc 25 cm. in diameter, pivoted on a vertical spindle and situated in a uniform magnetic field having a density of 3000 lines per sq cm. The driving current flows radially from the centre of the disc to the circumference When carrying a current of 10 amperes, there is a voltage drop in the disc of 2 volts, while the resistance of the circuit is found to be 0 196 ohm Calculate the speed of rotation of the armature disc and the power absorbed in friction. (*Whitworth*, 1927.)

20 The following data refer to the magnetization curve of a 4-pole direct-current series motor—

Flux per pole (megalines)	0 643	0 96	1 1	1 17	1 205
Ampere turns per pole	858	1715	2575	3430	4290

Each of the field coils is wound with 143 turns and has a resistance of 0 15 ohm. The armature has a two-circuit winding with 324 turns per circuit, the resistance of the winding, including brush contact resistance, being 1 17 ohms The resistance of the interpole winding is 0 3 ohm.

Calculate the speed-current and rotor torque-current curves for this motor when supplied at 440 volts

If the full-load output is 12 h p and the iron, friction, and windage losses at this output are 430 watts, what is the full-load speed ? (*Lond. Univ* , 1926, *El Mach.*)

28. D.C. Generators—External Characteristics

Magnetization Curve The volts produced on open circuit plotted as ordinates against either field amperes or ampere-turns as abscissae. The field should be separately excited, but in general the effect of obtaining the field current from the armature is negligible The voltage is directly proportional to speed at given excitation

Terminal P D. Line Lines drawn through the origin represent by their slope to the horizontal a resistance, i e. volts vertically over amperes horizontally. If such a line be drawn to represent the resistance of the shunt field, it will cut the magnetization curve at a voltage at which the machine will self-excite on open circuit, when driven at the speed for which the magnetization curve is drawn

External Characteristic A load current passing through the armature produces a drop in volts given by $I_a r_a$, which

is additive to the terminal volts to give the generated volts. To find both the latter for a given armature current, find the internal volt drop, and fit it vertically between the magnetization curve and the terminal volts line, which, up to a maximum value, can be done in two places By setting out along the abscissae a scale of load amperes, the curve between this latter and the terminal volts is obtained. i e the external characteristic.

Effect of Armature Reactions The demagnetizing effect of the armature currents, if present, must be subtracted, in ampere-turns, from the excitation, also in ampere-turns Thus each load current produces a volt drop, measured vertically on diagram, and a demagnetization effect, measured horizontally to the left The line representing their vector sum must, therefore, be fitted between the o.c curve and the p d. line, instead of the volt drop line only above Since each effect is proportional to load current, this line will always have the same slope

Effect of Compounding Here the series turns will contribute magnetizing ampere turns to the field, and thus the line representing this effect will be drawn to the right instead of to the left as above Otherwise the case is similar

EXAMPLES 28

1. What percentage rise in voltage at the terminals would you expect when full-load is thrown off a 150 kW 250 volt shunt-wound generator, running at constant speed, for which the following particulars are given—

(*a*) *No-load Magnetization Data*—

Field ampere-turns per pole	2000	4000	6000	8000	10,000
Armature volts	118	200	250	275	295

(*b*) *Armature Winding*—

180 coils, each having two turns, connected 4-pole lap Resistance 0·012 ohm.

(*A.M.I.E.E.*, *April*, 1921.)

2. The following magnetization curve was obtained for a D.C. generator run at normal speed—

Field amps	1	2	3	4	5	6	7
O C volts	140	235	310	372	423	468	505

If the field circuit is adjusted to 80 ohms resistance, and the resistance of the armature is determined as 0 15 ohm, plot the complete external characteristic

3 The following figures give the magnetization curve of a shunt generator for a speed of 550 r.p m —

Field amps	2	4	6	8	10
Volts	285	435	515	625	695

If the speed is raised to 650, and the field circuit adjusted to a resistance of 85 ohms, what voltage will be generated on open circuit?

4. In the above question, using the magnetization curve given for 550 r.p.m , and given a field circuit resistance of 80 ohms and armature resistance of 0 2 ohm, plot the complete external characteristic.

5 The relation between the excitation current and the electromotive force generated by a direct-current shunt-wound generator, running on open circuit at 850 r p m., is as follows—

Excitation amps	2	3	4	5	6
E M F generated (volts)	68	87	100 5	109	112 5

The shunt field resistance is 22 2 ohms. Find the voltage at the terminals of the machine when it runs at 850 r.p m. self-excited. (*Lond Univ.*, 1924, *El Tech*)

6 A direct-current generator is required to deliver 250 kW. The no-load voltage is 500 and the machine is to give 550 volts on full-load The open circuit characteristic is as follows—

Armature volts	500	525	550	585
Field ampere-turns per pole .	6000	6700	7500	9000

Assuming that the total resistance drop, excluding that of the armature itself, is 3 per cent of the net terminal voltage at full-load, and that the shunt field is connected across the brushes, estimate the number of series ampere-turns per pole required if commutating poles are provided The armature resistance is 0 04 ohm. (*Lond. Univ.*, 1927, *El. Mach*)

29. D.C. Generators in Parallel

EXAMPLES 29

1. Make a diagram of connections for two over-compounded C.C. generators connected to traction busbars and equalizer. What is the effect of having resistance in the cables leading

from the machine to the equalizer? How can you tell f the characteristics of the machine whether the resistanc the equalizer connections is too great?

(*C & G, Final*, 1920

2 Two shunt-wound 500 kW C.C. generators made different makers are driven by steam engines, also by diffe makers It is found that when the plant is adjusted so a share the load equally at three-quarter load, one machine ta much more than its share when the load on the station rea full value Give possible reasons for this behaviour W tests would you make to find out what is wrong and w alterations in the plant might be necessary in order to rem the defect? (*C & G, Final*, 1920

3 (*a*) What are the principal conditions which must satisfied if a shunt-wound dynamo is to be self-exciting w on load?

(*b*) How would you ensure the satisfactory operatior parallel of a number of shunt-wound dynamos?

(*c*) Why is an equalizing connection used when a num of compound wound dynamos are running in parallel?

(*A M.I E E, April*, 1921

4 Two 220 volt D C generators are operating in para One has an external characteristic which may be consider straight line from normal voltage at 35 amperes to 270 v at no-load The other has an external characteristic wl may be considered a straight line from normal voltag 50 amperes to 280 volts at no-load. Calculate the out current and voltage of each generator when the total out is (*a*) 60 amperes, (*b*) 20 amperes.

(*Lond Univ.*, 1927, *El. Tech*

30. D.C. Exciting Coil Design

Bedding of Wires Usual to assume that the wires directly on top of one another and not in the holl between other wires

Coil or Bobbin Relations. -

D_2 = extreme diameter of bobbin,

D_1 = diameter over insulated core,

h = depth of winding space $= \frac{1}{2}(D_2 - D_1)$

$\frac{1}{2}(D_2 + D_1)$ = mean diameter of winding space,

l_m = length of mean turn $= \frac{1}{2}\pi (D_2 + D_1)$

b = net length of winding space,

d = diameter of wire over insulation,

Then No of wires per layer $= b/d$

No of layers $= h/d$

No. of turns $= S = bh/d^2$.

Total length of wire $= Sl_m$.

Total cross-section of winding, including insulation,

$$= \frac{\pi d^2}{4} \times \frac{bh}{d^2} = 785 \times \text{winding space.}$$

Hence *space factor* $=$ 785 in this case

S C C Wires Used for Field Windings The covering increases the area of the wire and the following selected wires give the relative increase in area—

Old S.W G and diam in in	New Standards Diam in in	Net area in sq mils (New)	S C C increases area by about
16 (064)	064	3000	$\frac{1}{5}$
17 (056)			
18 (048)	044	1500	
19 (040)			
20 (036)	036	1000	$\frac{1}{4}$
21 (032)			
22 (028)	029	600	$\frac{1}{3}$

Excitation at Given Voltage It is frequently necessary to provide a given number of ampere-turns at a given voltage, e g in shunt windings.

If $V =$ volts p d. across coil,

$I =$ current in coil,

$R =$ resistance of coil,

then $R = \dfrac{V}{I}$ and $\dfrac{R}{S} = \dfrac{V}{IS} =$ resistance of a mean turn r_m.

If the mean turn can be closely estimated, the size of wire is obtainable, taking 0 8 microhm per in -cube or 2 microhm per cm.-cube as the specific resistivity of hot copper.

Total resistance of winding, $R = Sr_m$

Exciting current $I = \dfrac{V}{Sr_m}$, which should not exceed a density of 800 amperes per sq in

Then number of turns $S = IS/I$

Heating Check Watts lost in coil $= VI$

The exposed surface of the completed coil is estimated, and thence the watts lost per unit surface area This should not exceed 10 watts per sq dm or $\frac{3}{4}$ watt per sq in

Note If permissible watts are given, then obviously the exciting current at given voltage is $I =$ watts$/V$.

Series Windings The current being fixed by other considerations, it follows that S must equal IS/I A size of conductor is chosen (often strip) so that the current density is not in excess of 800 amperes per sq in, and the watts lost per unit radiating surface checked as above

EXAMPLES 30

1 Determine the diameter of copper in the wire of a winding to give 10,000 ampere-turns at 120 volts with a mean turn of 30 in.

2 Dimension a wooden bobbin to slide over a core $\frac{1}{2}$ in in diameter to produce 800 ampere-turns when excited at 50 volts The bobbin is to be 2 in in length overall, and the wood will be turned down to such a thickness that when lightly insulated the wall will everywhere be 0 1 in. thick.

3 (*a*) Show that the following relation holds for the conductor in any magnetizing coil—

Resistance per foot = volts across coil — L.M.T $\times$ ampere-turns where L.M T is the mean length of one turn in feet.

(*b*) Calculate a suitable field winding for a 4-pole, 220 volt shunt motor to give 4500 ampere-turns per pole, given that the poles are 5 in in diameter and the length of the winding is not to exceed 4 5 in. (*A.M.I E.E.*, *April*, 1921.)

4. A field coil, which has to produce 6000 ampere-turns, can dissipate 100 watts. The potential difference across its terminals is 50 volts and the mean length of a turn is 50 cm. Find the diameter of the wire. (Take the resistance of 1 metre of copper, 1 sq. millimetre in cross-section, as 0 02 ohm)

(*A M I.E E.*, *April*, 1922)

5. A 4-pole D.C motor has a mean length of turn on the field winding of 28 in. Calculate the necessary shunt-field

winding to give 3500 ampere-turns per pole hot on 220 volts, with a total loss not exceeding 440 watts.

(*A M I E E*, *April*, 1923)

6 A pole when insulated for the reception of a field coil has a winding space of $5\frac{1}{4}$ in. × 2 in.

A series coil is required of 95 turns to carry 60 amperes at a current density of about 1000 amperes per square inch.

Sketch out a design for such a coil, indicating the number of turns per layer, number of layers, insulation on the conductors and in the coil, and method of bringing out the ends

(*A M I E E.*, *April*, 1923)

7 Calculate the winding for a shunt field-coil for a direct-current motor from the following data motor, 4 poles; supply, 110 volts; net winding space per pole, 4 in × 2 in; length of mean turn, 20 in, required, 4200 ampere-turns per pole when hot. Determine the watts lost in each coil, which should be kept down to a minimum by filling the whole winding space available (*A M I E E*, *Oct*, 1923)

8 A field coil with 5000 ampere-turns is required for a pole 6 75 in diameter and 7 in long If the voltage on the coil is 110 and the allowable watt loss is approximately 100, estimate (*a*) the diameter of the wire required, (*b*) the dimensions of the coil on the assumption that the mean temperature rise will be 40° C. (*A M.I E.E*, *April*, 1924)

9. Why is it so much simpler to obtain inherent automatic voltage regulation in a dynamo than in an alternator? Find how many series turns per pole are needed on a 500 kW. compound-wound dynamo required to give 500 volts at no-load and 550 volts at full-load, the requisite ampere-turns per pole being 7900 and 11,200 respectively. The shunt winding is designed to give 500 volts at no-load when its temperature is 20° C. The final temperature is 60° C.

(*C. & G*, *Final*, 1923.)

10. A 4-pole 460 volt D.C generator has a pole core 16 cm. diameter and such that a winding space of 24 cm × 4 cm. is available. Design a shunt winding to give about 7000 ampere-turns per pole

11. Describe the general design of a homopolar dynamo for 4000 amperes at 6 volts, and show how to calculate the exciting coil for such a machine.

12. Establish a formula applicable to an electro-magnet winding in terms of the watts to be dissipated, the exciting voltage, the number of turns, the cross-section of the wire, the length of mean turn, the winding space, and the space factor.

Find the maximum number of ampere-turns that can be accommodated in a winding space of 150 sq. cm. at a winding factor of 62, with length of mean turn 2 metres The exciting voltage is 110 volts, the watts loading 5500, and the specific resistance of hot copper is 2 3 microhms per cm cube

13 The following particulars refer to a 50 kW, 4-pole, 250 volt, 600 r.p m shunt-wound generator armature winding two-circuit with 330 conductors; resistance of armature and interpole windings, 0 045 ohm; axial length of each shunt-field coil, 11 5 cm; mean perimeter of each shunt coil, 103 cm, depth of winding, 7 6 cm The magnetization curve on open circuit is—

Flux per pole (megalines)	3 5	3 8	4 08	4 3
Ampere-turns per pole	5000	6000	7000	8000

Neglecting the effects of armature reaction, calculate (*a*) the diameter of wire for the shunt-field winding, (*b*) the number of turns per coil, (*c*) the resistance of each coil, (*d*) the shunt-field current at full-load Take the specific resistance of copper as 2×10^{-6} ohm per cm. cube, and allow 5 mils radial thickness for insulation (*Lond Univ.*, 1926, *El Mach.*)

14. A lifting magnet is to be operated from a 200 volt direct current supply and to absorb 3 kW. Determine the maximum number of ampere-turns that can be provided, if the winding space has a cross-sectional area of 300 cm.², the mean length of turn being 1 5 metres Specific resistance of copper, 2 microhms per cm.³. Space factor, 0·7.

(*A M.I E.E*, *April*, 1927.)

15 A coil is to be wound on a cylindrical bobbin with a diameter of 3 cm. and a length of 8 cm. The radial depth of the winding space is 1 5 cm. The power taken by the coil is to be 100 watts when the terminal p.d. is 100 volts direct current. Assuming the insulated wire to have a space factor of 0 7 and the specific resistance of copper to be 2 microhms per cm. cube, find the number of ampere-turns that can be accommodated. (*C. & G.*, *Final*, 1927.)

16. A crane magnet is built to dissipate about 5 kW. at a supply voltage of 100 D.C. The net winding space is 20 × 20 sq cm Determine the number of turns in the magnet, the cross-section of the copper wire used, and the total ampere-turns, taking a winding space factor of 0·6, and a specific resistance, hot, of 2·3 microhms per cm. cube. The mean length of turn of the winding is 2 mt.

(*Lond. Univ.*, 1927, *El. Mach.*)

31. D.C. Armature Reactions and Series Interpoles

Reference *Continuous Current Machines*, by S P Smith (Benn).

The series interpole is required to neutralize the cross-flux from the armature, and in addition to provide a commutating flux of such a value that the rotational E M F. generated by it in the coil undergoing commutation shall equal the E M F of self-induction produced in the coil by the very act of commutation

Armature Cross Ampere-Turns

$$\left.\begin{aligned} Zi_a/2p &= \text{ampere-conductors per pole} \\ Zi_a/4p &= \text{ampere-turns per pole} \end{aligned}\right\} \text{producing cross-flux}$$

If the brushes are advanced through an angle θ, which should not be the case with interpoles, then

$\dfrac{2\theta}{360} Z =$ conductors producing demagnetizing flux per pole,

$\dfrac{\theta Z}{360} i_a =$ ampere-turns of demagnetization per pole, and this expression must be subtracted from the cross ampere-turns above, to give the net number of ampere-turns to be added to the interpoles to nullify cross-flux

The E M F of Self-induction in coils undergoing commutation will depend upon the coefficient L for the coils and the speed of reversal of the current, i e the " frequency of commutation "

Estimation of Coefficient L Hobart's Rule For open slots, the embedded length of a turn is linked with 4 lines of force per ampere per cm , while the free end turns link with about 8 lines of force per ampere per cm In the slot, the conductors are always in pairs, with currents normally in the same direction, so that the second conductor produces another 4 lines, linking with the first conductor Hence

if l_1 = embedded length of a turn,

l_2 = free length of a turn,

then $8l_1 + 8l_2$ = flux per ampere linking with one turn

If T_c = turns per coil

m = number of coils short-circuited by the brushes,

then $T_c\ (8l_1 + 8l_2)$ = flux per ampere linked with each turn.

and $T^2_c\ (8l_1 + \cdot 8l_2) \times 10^{-8}$ henrys = coefficient L of one coil

If the whole group of m coils lies in the same slots, the coefficient becomes

$$L = mT^2_c\ (8l_1 + 8l_2)\ 10^{-8} \text{ henrys}$$

Frequency of Commutation Complete commutation can be regarded as equivalent to half a complete cycle of A C

If v_c = peripheral speed of commutator,

t_b = arc of brush contact (or thickness of brush),

t_m = thickness of mica insulation,

then $\frac{t_b - t_m}{v_c}$ = time for commutation, T,

and frequency $f = \frac{1}{2T} = \frac{v_c}{2\,(t_b - t_m)}$, reducing to $\frac{v_c}{2t_b}$ approximately if t_b be taken as the brush thickness instead of the arc of contact

Then *E M F of self-induction* $E_s = 2\pi f L i_a$ per coil.

Commutating Flux Now the short-circuited coils must move in a commutating flux of density B_c, extending over an axial length of L_c, such that the *rotational E M.F*, $E_c = 2T_c v L_c B_c\ 10^{-8}$ shall $= E_s$ above, where v = velocity of coil side

Ampere-Turns for Commutating Flux It is customary to calculate the ampere-turns to push the commutating flux across the air-gap only Alternatively 25 per cent is added to the ampere-turns per pole of cross-flux from armature to give the total ampere-turns for the commutating pole The excitation current is the armature current if all the interpoles are in series, or a sub-multiple if they are arranged in parallel groups.

EXAMPLES 31

1 The following data refer to a generator with a full-load current of 600 amperes: conductors, 512, arranged 6-pole

wave; commutator segments, 128 If the brushes are rocked forward a distance equal to 3 commutator segments from the neutral position, find the number of ampere-turns to be placed per pole on the interpoles to compensate the cross-flux.

2 Discuss the question of limiting value of the reactance voltage in the case of a direct current armature Obtain a formula by means of which the reactance volts may be estimated Estimate the reactance voltage for the machine of which the following particulars are known number of commutator segments, 55, revolutions per second, 11 67; brush width in commutator segments, 1 74; coefficient of self-induction, 0 000153 henry; current per coil, 27 amperes

(*A M I E E*, *Oct*, 1924.)

3 Explain the function of the interpole as used for commutating purposes, and show how to estimate the field required to effect commutation when data of the armature winding are available

If a single-turn armature coil as short-circuited by the brush has a resistance of 0 015 ohm and an inductance of 0 015 millihenry, find what commutating field would be required to enable a current of 20 amperes to be "straight-line" commutated in one-thousandth part of a second.

4 Describe the construction and principle of action of a dynamo suitable for train lighting, emphasizing what happens on reversal of motion How is such a machine suitable for the running of an arc lamp without the employment of a ballast resistance? (Rosenberg's dynamo.)

5 Show by means of curves and rough sketches the distribution of flux that would be obtained in a C.C shunt motor on load if fitted with interpoles, and also what the distribution would be if the interpoles only were excited

✓6 Estimate the number of turns needed on each commutator pole of a 6-pole, lap-wound dynamo of 200 kW. at 200 volts, given · armature diameter, 90 cm.; total number of armature conductors, 540; length of commutating-pole air-gap, 1 cm.; flux density in commutating-pole air-gap, 3000 lines per sq cm (*A.M I.E.E*, *Oct*, 1922)

32. D.C. Motor Starters—Calculation of Resistance Elements

References. *Electric Switch and Control Gear*, by C. C. Garrard (Benn). *Controllers for Electric Motors*, by James (Chapman & Hall)

An overload of about 40 per cent is usually allowed for

starting purposes, and the starter will be advanced a step when the current has fallen to a definite lower limit If this lower limit is specified, then the number of steps must be adjusted to suit these working limits. If the number of steps is specified, then the lower limit current will be fixed thereby

The resistances in circuit on successive studs form a geometric progression, having as its common ratio the value–lower limit/upper limit

Let V = supply voltage,
R_1 = resistance in circuit on first stud, including motor and leads,
then I = upper limit current $= V/R_1$
If i = lower limit current, and
r = ratio of i/I,
then R_2 = resistance in circuit on second stud,
$$= R_1 \times r$$
R_3 = resistance in circuit on third stud,
$$= R_2 \times r = R_1 \times r^2$$
whence R_n = resistance in circuit on nth stud,
$$= R_1 \times r^{n-1}$$

Suppose there are $n + 1$ studs, giving n steps, so that the resistance in circuit on the last stud is just the resistance of the motor, R_a (The armature resistance only is generally taken as the only resistance in circuit)

Thus we have the equation $R_a = R_1 \times r^n$,
whence r is found if n is given, or
n is found if r is given.

In this latter case, n need not be found by solution of this equation, as the G P will cease when the resistance of the armature is reached, and then the number of steps can be counted up.

Series Motors The above treatment really applies to shunt motors only, working in a relatively constant field. For series motors, the back E.M.F. increases on passing from one stud to the other, due to increased field (speed

momentarily constant), whereas in the shunt motor the above treatment is based on constant back E M F on passing from one stud to another It, therefore, follows that resistance can be cut out more quickly for a series motor than for a shunt motor, but a starter designed for a shunt motor will be available (and conservatively rated) for a corresponding series motor For a special treatment for series motors, we have the *analytical treatment due to S P Smith* (see *Journal, I E E*, Vol 58, page 645) The magnetization curve of the motor is required, or the speed load curve

If I = upper limit current, i = lower limit current; $k = \dfrac{I}{i}$, i e current increment factor,

Φ = pole flux corresponding to I, ϕ = pole flux corresponding to i; $B = \dfrac{\Phi}{\phi}$ = flux increment factor,

α = B/k = flux – current increment factor,

R_1 = *total* resistance in circuit on first stud, including motor,
R_2 = ditto on second stud, ditto; $r_1 = R_1 - R_2$,

R_m = resistance of motor, including field,

V = supply voltage,

n = number of resistance steps or sections,

then, if the motor is to start with current I on first stud, the condition to be satisfied is that the function

$$f = (B - \alpha)\frac{1 - \alpha^n}{1 - \alpha} + \frac{I}{V}R_m - 1 = 0$$

and the first *section* of the resistance is $r_1 = R_1 (B - \alpha)$.

Succeeding *sections* of resistance form a geometric progression with common ratio α, i e $r_2 = \alpha r_1$, $r_3 = \alpha r_2$, etc

If n is given, then i will not be, and vice versa In the former case, which is the most usual, it is necessary to find, by trial and error, what lower limit of current i will satisfy the above condition

If the speed load curve is given, deduce the ideal speed curve, i e when $R_m = 0$, by adding $R_m I$ to the speed ordinates. Then, since back E.M F, $E = V$ = constant

for this ideal curve, it follows that the flux is inversely proportional to the speed, or Φ/ϕ = speed corresponding to i/speed corresponding to I

EXAMPLES 32

1 State clearly what information you would need to enable you to calculate a metallic starter with a given number of steps for a series motor. Calculate the resistance steps for the starter of a 500 volt shunt motor, given · number of steps, 12; maximum current during starting, 20 amperes, resistance between armature terminals, 1 ohm

(*C & G*, *Final*, 1921.)

2 A starter is required for a 10 h p, 220 volt shunt-wound motor. The armature resistance is 0 02 ohm Give particulars of the resistances of the various steps, and state the resistance material you would use, and the method of support you would adopt (*A.M.I E E.*, *April*, 1923.)

3 Obtain the number of steps and the resistance in each step of a starter for a 500 volt motor on the assumption that the resistance of the armature is 0·125 ohm The maximum permissible value of the current is 100 amperes, and resistance is cut out when the current has fallen to 70 amperes.

(*A.M I.E.E*, *April*, 1924)

4 A 200 h p shunt-wound motor with an armature having resistance of 0·25 ohm is to be started from 480 volt D.C supply mains. Calculate the resistance required for each step of the starter if there are 5 steps on the starter, and the maximum current shall at no time exceed 450 amperes.

(*Lond Univ*, 1922, *El. Power.*)

5 What materials are employed for the resistance sections of metallic starting rheostats, and in what forms should these materials be used in starters for (1) a 2 h p., 220 volt motor, (2) a 25 h.p, 500 volt motor, and (3) a 60 h p., 110 volt motor?

Each grid of a grid-type rheostat has overall dimensions (exclusive of connecting lugs and bosses) of 17 4 cm × 23 5 cm, and a thickness of 0 9 cm, the specific resistance of the material being 86×10^{-6} ohm per cm. cube Make a dimensioned sketch of a grid for which the resistance is 0 012 ohm and the cross-section of conductor is 0 85 cm. Show by sketches how the grids are assembled in a common frame, giving details of the insulation and how the series or parallel connections are made between individual grids.

(*Lond. Univ*, 1923, *El. Mach*)

6. Estimate the resistance sections for an 8-stud starter for

a 15 h.p , 440 volt D C shunt motor, the armature drop on full-load being 7 per cent of supply voltage, the current on the first stud being limited to full-load value and the current not to exceed 150 per cent of this on succeeding studs.

7 A direct-current, 500 volt series-wound motor, having a resistance of 0 5 ohm, gave the following figures when tested on load at the rated voltage—

Revolutions per minute	160	140
Current in amperes	40	50

If the motor is started from rest by means of a variable series resistance, calculate (*a*) the total resistance *R* required in the circuit of the armature if the current at starting is to be 50 amperes, (*b*) the speed when the current has fallen to 40 amperes, the total resistance being kept constant at *R* ohms, (*c*) the value of the resistance to be cut out at this speed which will cause the current to increase to 50 amperes again Sketch and describe a starter suitable for this.

(*Lond Univ* , 1925, *El Power*)

8. It is required to supply a resistance of 50 ohms with eight equal increments of current in successive steps, starting from zero current. At the final step the resistance is to be on full-line voltage. Intermediate steps are to be obtained by moving one of its terminals to successive taps on another resistance of 200 ohms, connected permanently across the line voltage Calculate the values of the sections into which the resistance of 200 ohms must be divided.

(*Lond. Univ.*, 1926, *El. Tech.*)

9 Calculate a starter for a 10 b.h.p , 440 volt series crane motor given the following data—

Magnetization curve—

Amperes	5	10	15	20	25	30
Pole flux (megalines)	1 75	2 75	3 42	3 94	4 3	4 6

Upper limit current, 28 amperes.
Number of steps, 5 Resistance of motor, 1 1 ohm

10. Explain briefly the reason why a satisfactory starter for a series motor can be obtained with fewer studs than would be required for a corresponding shunt motor. Assuming that the magnetization curve is a straight line passing through the

origin, calculate the values of the resistance elements for the starter of a series motor from the following data—

Voltage	500 volts
Maximum starting current	100 amperes
Motor resistance	0.5 ohm
Number of elements	5 (i e 6 studs)

(*Lond. Univ*, 1923, *El. Mach*)

11 Show how to find the resistance steps for the starter of a series-wound direct current motor A 40 b.h p, 400 volt series motor has an efficiency of 0.88 and a resistance of 0.75 ohm Find the resistance steps for its starter if there are 5 steps and the maximum current is to equal the full-load current on each step The magnetization curve is as follows—

Current	42.5	51.0	60.2	78.5	97.5 amperes
Flux	5.0	5.5	6.0	6.5	7.0 megalines

(*Lond Univ*, 1927, *El Mach.*)

33. D.C. Shunt Motors—Field Regulators

EXAMPLES 33

1 Obtain the values of the resistances between stops on a shunt-field regulator for the 460 volt D C motor whose open-circuit characteristic is given in the appended table, and whose no-load speed has to be increased from 500 to 1000 r.p.m. by 5 equal increments—

Field amperes	1	2	4	6	8
Open-circuit volts	200	300	400	460	500

(*A M I E E*, *Oct.*, 1924)

2 A 230 volt D C shunt-wound motor whose magnetization curve is given by the figures below, runs at no-load at 1200 r p m The resistance of the field magnet coils is 38.3 ohms. Find what resistance must be placed in series with the field magnet coils to increase the speed to 1100 r.p.m. at no-load—

Amperes in magnet coils	1	2	2	4	5	6
Flux per pole in megalines	0.44	0.8	1.02	1·15	1.21	1.24

(*Lond Univ*, 1923, *El. Tech*)

3 A shunt generator is required to give an output of 300 kW at a terminal voltage, which may be adjusted to any desired value between the limits 210 to 230. The machine is also required to run on a 25 per cent overload for 2 hours, the terminal voltage being adjustable over the same range.

The resistance of the field winding is 16.9 ohms at 20° C.

and the relation between the electromotive force and field current at normal speed is as follows—

Field current	5 04	5 77	6 75	8 02	10 3	14 2
Electromotive force	190	210	230	250	275	300

When the machine was running on a 25 per cent overload at normal speed, and with a terminal voltage of 230, the field current was 10 2 amperes

Find the resistance necessary in the field regulator on the assumption of a maximum temperature of 60°C, and show how the resistance steps should be graded to give equal increments of terminal voltage per step with the machine running at the normal speed on no-load and at a temperature of 20° C

(*Lond Univ*, 1925, *El Mach*)

34. D.C. Machines—Leading Dimensions

If D = diameter of armature core in in or cm,
L = gross length of armature core in in or cm,
W = watts output or input,
N = speed in r p m.,
G = output coefficient,
= $W/D^2LN = \pi^2 B\tau X/60 \times 10^8$, where
B = gap flux density,
τ = ratio pole arc to pole pitch,
X = specific ampere loading

TYPICAL DATA FOR MULTIPOLAR MACHINES

Item	Symbol	English	Metric
Output coefficient			
from W/N = 100	G	42×10^{-3}	26×10^{-4}
to W/N = 1000		48×10^{-3}	29×10^{-4}
to W/N = 5000		52×10^{-3}	32×10^{-4}
Specific ampere loading .	X	750	300
Flux density in teeth .	B_t	135,000	20,000
field core	B_f	100,000	13,500
armature core	B_a	80,000	11,000
yoke (cast steel)	B_y	80,000	11,000
pole shoe	B_s	60,000	10,000
air gap	B	50,000	8000
yoke (cast iron)	B_y	35,000	5000
Current density in slot copper		$2600a$	$4a$/sq mm.
Commutator pitch, about		2 in.	7–10 mm

Ratio pole arc/pole pitch		about ·7
Commutator volts per segment		about 15
Total current per slot	up to about 1000A	
Hysteresis loss W_h	1·95 × $10^{-10} f B^{1.6}$	watts per c.c.
Eddy current loss W_e	·78 × $10^{-11} B^2 f^2 t^2$	watts per c.c.

References *The Dynamo*, by Hawkins (Pitman); *Continuous Current Machines*, by S. P. Smith (Benn Bros.); *Electric Motors*, Vol. I, by Hobart (Pitman); *Specification and Design of Dynamo Electric Machinery*, by Miles Walker (Longmans, Green & Co.); *The Performance and Design of Direct Current Machines*, by Clayton (Pitman).

EXAMPLES 31

1. In what way would you drive a 2000 kW. direct current generator from a steam turbine running at 3000 r.p.m.? State what you consider to be a suitable diameter and length of armature core for the dynamo.

(*A.M.I.E.E.*, *April*, 1924.)

2. Obtain a first approximation to the leading dimensions of a D.C. generator having an output of 1000 kW. on full-load at 500 volts. The machine is to have interpoles and operate at 250 r.p.m. with the usual B.E.S.A. temperature rises.

(*A.M.I.E.E.*, *Oct.*, 1925.)

3. Obtain a first approximation to the leading dimensions of a 4 pole, 75 kW. D.C. generator operating at 750 r.p.m. and giving 525 volts on open circuit. Assume suitable values for the air-gap density, ampere conductors per unit length of periphery, etc. (*A.M.I.E.E.*, *April*, 1924.)

4. The output of an armature is given by

$$\text{kW.} = D^2L \times \text{r.p.m.} \times G$$

Assuming a suitable value for the output coefficient (G), give the leading dimensions for the armature core of a 500 volt D.C. generator to develop 50 kW. at 500 r.p.m.

(*A.M.I.E.E.*, *April*, 1924.)

5. Make the necessary calculations in order to arrive at a first approximation to the design of a 100 b.h.p., 500 volt D.C. interpole motor to develop its full output at a speed of 600 r.p.m. Assume suitable values for flux and current densities, etc., and state the working temperature rise to be expected.

(*A.M.I.E.E.*, *April*, 1925.)

6. Make the necessary calculations in order to arrive at the leading features and dimensions of a 50 b.h.p., 4 pole D.C.

shunt motor fitted with interpoles and intended to operate at 800 r p m. on a 500 volt supply

(*A M.I E E* , *Oct* , 1924)

7 Designs are required for a line of direct current 4-pole motors for the following outputs and speeds—

Output	Speeds in revolutions per minute
5 horse power	2000, 1500, and 1000
10 ,,	1500, 1000, and 600
15 ,,	1500, 1000, and 600
20 ,,	1500, 1000, and 600

From the following table of output coefficients work out the diameters and core lengths of the armatures of these machines—

Horse power output	5	10	15	20
$\frac{W}{D^2LN}$	0 00091	0 00122	0 00146	0 00169

Where W denotes the output in watts, D the diameter of the armature, and L the net core length in centimetres, N the revolutions per minute

(*Lond Univ* , 1925, *El Mach*)

8 A 30 b.h p , 160 volt, 4-pole shunt motor fitted with interpoles has been designed to operate at 700 r p m Make freehand sketches showing the constructional details and the dimensions of a commutator suitable for this motor.

(*A M I E E* , *April*, 1924.)

9. Design and draw the armature of a compound-wound D C generator to run at a speed of 375 r.p m , and to comply with the following specification—

Output	500 kW
Voltage	250
Regulation	The machine to be compounded from 240 volts no load to 250 volts full-load
Commutation	Sparkless at all loads without rocking the brushes
Temperature rise	Not to exceed 45°C by thermometer after 6 hours' full-load run
Test voltage to earth	1500 volts for 1 minute

The efficiency at full-load and half-load, calculated from the no-load losses, to be stated

(*Lond Univ.*, 1921, *El Mach*)

10. Make the necessary calculations in order to arrive at a first approximation to the design of the commutator and brush gear for a D.C. interpole generator having an output of 1000 kW on full-load, at 500 volts, 250 r p m. Assume a surface temperature rise of 50° C (*A M I E E* , *April*, 1926)

35. Batteries and Boosters

EXAMPLES 35

1 Give a short account of essential matters in the maintenance of a large battery Explain the nature of sulphating, refer to the removal of deposit, the attention to be paid to density, the protection of parts or fittings liable to corrosion, the signs of good condition, and similar practical points

(*C & G*, *Final*, 1925)

2 Describe the construction of the Edison alkali accumulator, and give the chemical changes taking place during use Compare and contrast it with the lead-acid cell under the following heads (1) weight, (2) voltage, (3) charging peculiarities, (4) maintenance, (5) suitability for traction, (6) cost for given watt-hour capacity

3 Describe any form of automatically reversible battery booster, showing its connection in the circuit, and state clearly how it functions, and how it is adjusted to so function at any desired load conditions.

4. Describe and compare the "end cell" and "reversible booster" methods of working a battery, assuming (*a*) normal working conditions, and (*b*) a breakdown of the converting plant in the sub-station (*A.M.I.E E*, *Oct*, 1923)

5 A 55 cell, 420 ampere-hour lead battery costs £520, the energy put into the battery costs 2d per kilowatt-hour; determine approximately the cost of the output energy per kilowatt-hour, assuming that the battery plates will last for 800 cycles of charge and discharge, and that the watt-hour efficiency is 70 per cent. Give your own figures for proper maintenance costs, and state briefly your views as to the actual useful life of lead cells. (*A.M I E.E*, *Oct.*, 1925.)

ANSWERS TO QUESTIONS

VOL. I

EXAMPLES 1

1. 0 0168 ohms **2** 0 357 ohms **3.** 49 8 yd **4.** 8 59 microhms/cm ³ **5.** 0 1377 cm **6.** 1 1 microhms/in ³

EXAMPLES 2

1. 8 ohms **2.** 200 volts 1 68 kW , 114 volts **3** 216 6 ohms. **4** 1,4 , 0 9 amps **5** 9 4% , 9 35 % **6.** 25 , 8 34 , 4·16 and 2 5 ohms , 62 5 , 250 , 562 5 and 1000 watts **7.** 0·00634 ohms , 4 06 kW

EXAMPLES 3

1. 1 kW , 2d **2** 70 % , 85 1 kWh **3.** 3 96d and 6 4d. **4.** £1,213 3 , 4 03 % **5** £251

EXAMPLES 4

1. Copper, 0·532 sq in , 28 9 tons Aluminium, 0·852 sq in ; 14 2 tons **2.** (*a*) 24·3 volts , (*b*) 2 3 kW , (*c*) 2 06 tons **3** 75 1 miles **4.** 548·9 volts , 1·11 tons **5** 0 64 ohms **6.** 491 volts , 7 kW , 2 42 tons Use 37/ 103, i e 0 3 sq in cable.

EXAMPLES 5

1 0 9 , 0 5 , 0 4 amp , $g = 0\ 45$ mho **2.** 0 542 mho , 5 42 amp. , 32 5 % **3.** 44 41 volts , 98, 73 3, 148 7 and 124 1 watts [illegible] total, 444 1) **4.** 8 825 volts , 39, 26, 19·5, and [illegible] 100 watts). **5.** 0·937 amp , 28 4 watts. **6** 19 ohms , 9 ohms **7.** 15 88 volts , 1 304 amp. , 10 62 watts. **8** $W = VI = V^2/R = V^2G$, whence $G = W/V^2 = 500/2500 = 0\ 2$ mhos Individual G's are $1/15 = 0{\cdot}0666$ and $1/25 = 0{\cdot}02$, totalling 0·1066 Thus the third conductance is $0\ 2 - 0{\cdot}1066 = 0{\cdot}0933$, corresponding to a resistance of 10 7 ohms. *Ans* Alter, total current = 500/50 = 10 amp Current through 14 ohms = 3·57 amp , through 25 ohms = 2 amp , totalling 5·57 amp , leaving a balance of 4·43 amp , which will be passed by 50/~~6·93~~ 4.43 = 11·3 ohms.

EXAMPLES 6

1. (*a*) 0·48 amp. , (*b*) 0 54 amp. **2.** (*a*) 2 24 and 7 watts , (*b*) 0·466 and 583 watts. Two || groups of 2 each give 0·81 watts output. **3.** (*a*) 3 parallel groups of 2 cells each connected to 2 parallel groups of 2 resistances each gives 0 362 amp and 0 705 watts

output, (*b*) all cells and resistances in parallel gives 0 667 amp and 0·6 watts output **4.** 1·44, 0 96 and 0 72 amp **5** 3 86 volts **6.** 2 parallel groups of 3 in series gives 0 7 amp **7.** (*a*) 12 15 amp, (*b*) 3 67 amp, (*c*) 2 parallel groups of 6 in series gives 13 4 amp

EXAMPLES 7

1. $ab = 0\ 282$, $ad = 0\ 318$, bc 0 23, cd 0 37, bd 0 052 amp **2.** $ab = 1\ 164$, $ac = 0{\cdot}809$, bc - 0·019, bc 0 669, bd -- de = 0 446, ce = 0·858 amp **3.** ab -- 0 5, bc 0 5, ad - 0 765, $dc = 0\ 735$, $ae = 0\ 32$, ce 0 35, de 0 03 amp **4** 0 015 amp **5.** 12 amp discharge from 110 volts, 30 4 amp charge through 100 volts, total 18 4 amp from mains **6.** 0 0206 milliamps

EXAMPLES 8

1. 13 64 ohms (approx) **2.** 7·17° C

3. $50 = R_0(1 + 15\alpha)$ $\quad \frac{50}{55} \quad \frac{10}{11} \quad \frac{1 + 15\alpha}{1 + t\alpha}$ where t final temperature
$55 = R_0(1 + t\alpha)$

hence $10 + 10\,t\alpha = 11 + 165\alpha$

$$10\,t\alpha = 1 + 165\alpha \text{ or } t\alpha \quad \cdot 1 + 16{\cdot}5\alpha \text{ or } t = \frac{1}{\alpha} + 16\ 5$$

$$t = 23\ 4 + 16{\cdot}5 \quad 39{\cdot}9^\circ \text{ C} \quad \textit{Ans}$$

By the approximate method, 55 - 50 $(1 + t'\alpha)$ where t' rise of temperature Thus 5 = 50 $t'\alpha$, whence t' 23 4 and final temperature = 15 + rise 15 + 23·4 = 38 4° C

4. 47° C **5** 0·00298 **6.** 335° C

EXAMPLES 9

1 0 2 dynes or lines per sq cm **2** 0 4 **3.** 2 51 **4.** 9 42 **5.** 68 4 cm **6.** 0 158 **7.** 1 074 amp **8.** 1 13 gauss **9.** 720 dynes.

EXAMPLES 10

1. 99 **2** (*a*) 5 33, 6 66; 4·44; (*b*) 2·66 amp. **3.** 1,133. **4.** Flux density - 120,000/8. For iron, H $\frac{120{,}000/8}{100/8}$ = 1,200

$S\,I$ for iron $= \frac{10 \times 100 \times 24\pi}{4\pi \times 8}$ 750 (small piece of iron missing is neglected)

$S\,I$ for air $= \frac{10 \times 120{,}000 \times 0{\cdot}3}{4\pi \times 8}$ 3,580 Total 4330. *Ans.*

5. 5,880 amp.-turns For Carter's Coef., see *Electrical World*, vol. 38, 1901, p 884. Also *Continuous Current Machines*, by S. P Smith (Benn), p. 53. **6.** (*a*) 5,325, (*b*) 2,124. **7.** 4,460.

8.

Flux·	8	10	14	18	20	22	10^4 lines
Amperes·	5·2	6·48	9·26	11·21	18·09	25·72	

9. 2·77 amp

EXAMPLES 11

1. $Q = 0{\cdot}1504\ I$ **2** (*a*) 0·6061 megalines, (*b*) 1·118

3

Gap	1	2	3	4	5	7	10	15	20	25
Flux	1,270	1,080	988	894	819	687	494	273	127	56

4. $B = 14{,}286$, $\mu = 1{,}138$ **5** (*a*) 3,400, (*b*) 1·0, (*c*) 0·00182

EXAMPLES 12

1. 0·0203 henry   **2.** 18·82 micro-henrys   **3.** 0·16 henry
4. 0·1627, 0·478 and 0·278 henry   **5.** 120 henrys

EXAMPLES 13

1. 64 sq cm (each pole)   **2.** 2·42 amp   **3.** 152 lb.
4 4,710 lb, 1065 joules

5. $$F = \frac{2\ B^2 a}{2{\cdot}47 \times 10^7}\ \text{kg.} = \frac{2\Phi^2}{2{\cdot}47 \times 10^7 \times a} = 340\ \text{kg}, \quad \text{whence}$$

$\Phi = 0{\cdot}324$ megalines   *Ans* (*a*), (*b*) about 3 cm

6. 1,514. **7** 892 lb.

EXAMPLES 14

3. 0·00126, 0·00137, 0·00136

EXAMPLES 15

1 565 sq cm of plate   **2** 1418 $\mu\mu$F

3. 4×10^{-10} coulombs $= 4 \times 3 \times 10^{-1}$ c g s units $= 1{\cdot}2 = \sigma$

Flux density $\dfrac{4\pi\sigma}{\varepsilon} = \dfrac{4\pi 1{\cdot}2}{3{\cdot}3} = 4{\cdot}57$ lines/sq cm   *Ans*

Voltage $= F \times d = 4{\cdot}57 \times 0{\cdot}02 = 0{\cdot}0914$ c g s *E-S* volts
$= 0{\cdot}0914 \times 300 = 27{\cdot}42$ practical volts   *Ans*

Working in practical units, and per sq cm of condenser, we have for the capacity—

$$\frac{\varepsilon}{4\pi d}\ \text{cm} = \frac{\varepsilon}{4\pi d} \times \frac{10}{9}\ \mu\mu\,\text{F} = \frac{\varepsilon \times 10}{4\pi d \times 9 \times 10^{12}}\ \text{F}$$

$$\text{Then } q = CV \text{ or } V = \frac{q}{C} = \frac{4 \times 10^{-10} \times 4\pi d \times 9 \times 10^{12}}{\varepsilon \times 10}$$

$$= \frac{4 \times 10^{-10} \times 4\pi \times 0{\cdot}02 \times 9 \times 10^{12}}{3{\cdot}3 \times 10} = 27{\cdot}42\ \text{volts}$$

4. $$C \text{ per cm. length} = \frac{4}{2 \times 2{\cdot}3 \times \log_{10} 1{\cdot}1}$$

$$= \frac{4}{4{\cdot}6 \times {\cdot}0414} \times \frac{10}{9}\ \mu\mu\,\text{F}.$$

$= 23{\cdot}4\,\mu\mu$ F. per cm length or 2340 $\mu\mu$ F per metre   *Ans.*

$$Q = CV = \frac{2340 \times 20{,}000}{10^6} = 46{\cdot}8 \text{ micro-coulombs.} \quad \textit{Ans}$$

5. 0·0099 μF   **6** 739 μF.   **7.** 0·0002256 and 0·000271 joules, 2682 and 1610 volts/cm.

EXAMPLES 16

1. 30,400 coulombs, 8 45 amp **2.** 5 08 amp. **3.** 0 001118. **4.** 120 watts, 17,280 calories **5.** 1 8% slow **6.** 23 74 hr. **7.** Copper 1/2, chlorine 1/1

EXAMPLES 17

1. 9 **2** 0 398 ft -candles

3.

Feet	0	4	8	12	16	20	24
Illm.	0 25	0 236	0 2	0 16	0 119	0 0885	0 0655 ft -cdls

4. Short side, 14·58, long side, 14 1, centre of rect, 15·32 ft.-cdls. **5** 18 26 **6.** 15 95, 0 874 **7.** 45 1, 46·9 **8.** 3·78 ft, 0 595 mils. **10** 0·264 ft -cdls **11.** 3 2 ft -cdls **12.** (*a*) 1900d, (*b*) 51·7d, (*c*) 46 9d **13.** J inversely proportional to $\cos^3$ **14.** 1 24, 0 614; 0·296 **16.** (2) 7, (3) 0 7 ft -cdls **17.** d = 1 58 mil, l = 2·53 ft. **18.** Volts 4% up, c p 19 2% above normal, volts 4% down, c p 16 75% below normal **19.** 2 54 c p.

EXAMPLES 18

1. (*a*) Uncovered, 10 64 kW., covered, 8·7 kW, (*b*) 69·5%, (*c*) 85% **2.** (*a*) 3·175 hr, (*b*) 15 88d. **3.** 0 4 kW **4.** 3·4 min **5.** 23 7° C per min **6.** 56° C **7.** 0·41. **8.** 54 min **9.** 36%. **10.** 15 26 ohms, 0 528d **11.** 47 2 amp **12.** 90 grm **13.** 0 85 and 0 91 **14.** (*a*) 74·4 ohms, (*b*) 0·1085 units

EXAMPLES 19

2 20% overload **3** 0 023° C per sec **4.** 63 5° C, 1 94 hr, 16 12° C (Curve is very poor, results very variable)

5. See Fig 2, page 30, for graphical solution By calculation, we have, using the 1 and 2 hr figures—

$$29\ 2 = \theta_f\left(1 - e^{-\frac{1}{T}}\right) = \theta_f(1-y) \quad \text{where } y = e^{-\frac{1}{T}}$$

$$44\ 2 = \theta_f\left(1 - e^{-\frac{2}{T}}\right) = \theta_f(1-y^2)$$

By division of second by first, we have—

$$\frac{44\ 2}{29\ 2} = 1 + y, \text{ whence } y = 15/29\ 2 \text{ and } e^{\frac{1}{T}} = \frac{1}{y} = \frac{29{\cdot}2}{15} = 1\ 946$$

$$\text{whence } \frac{1}{T} = \log_e 1\ 946 = 2\ 3 \log_{10} 1{\cdot}946 \text{ or } T = 1{\cdot}5 \text{ hr.} \quad Ans.$$

$$\text{Also } \theta_f = \frac{29\ 2}{1-e^{-\frac{1}{T}}} = \frac{29\ 2}{1-y} = \frac{29{\cdot}2}{1-\frac{15}{29\ 2}} = \frac{29{\cdot}2^2}{14{\cdot}2} = 60^\circ \text{ C} \quad Ans$$

For temperature at end of 1 hr. run, we have (the time constant being the same)—

$$\theta = 45\left(1 - e^{-\frac{1}{T}}\right) = 45\left(1 - \frac{15}{29{\cdot}2}\right) = \frac{45 \times 14{\cdot}2}{29{\cdot}2} = 21{\cdot}9^\circ \text{ C} \quad Ans.$$

6. (i) T = 1·45 hr, (ii) t = 1·38 hr. = 83 min. **7.** T = 2 0 hr. θ_f = 65° C. θ for 1 hr run = 21·7° C **8.** T = 120 min., θ_f = 65° C.

EXAMPLES 20

1. 89·6, 90 9, 91 0, 90 6 %, 91 kW **2.** 87 95 %.

4. Field loss = 230 × 1·25 = 287 5 watts

Constant "light" losses = 227·5 × 3 4 = 773 6 watts

If η = efficiency, then full-load current $= \dfrac{10 \times 746}{230 \times \eta}$

Copper losses at full-load $= I^2 r_a$

$$= \left(\frac{7460^2}{230\,\eta}\right) \times \frac{5}{80} = \frac{746^2}{23^2 \times 4^2 \times \eta^2} \text{ watts}$$

$$\text{Hence } \eta = \frac{\text{output}}{\text{output + losses}} = \frac{746 \times 10}{7460 + 287\ 5 + 773{\cdot}6 + \dfrac{746^2}{92^2\eta^2}}$$

$$\text{whence} \qquad 8521\eta^2 + \frac{746^2}{92^2} = 7460\eta$$

$$\eta^2 - \ 875\eta + \ 00796 = 0$$

$$\eta = \frac{{\cdot}875 \pm \sqrt{{\cdot}875^2 - 4 \times \ 008}}{2} = \frac{{\cdot}875 \pm \ 856}{2} = \ 866 \text{ or } 86\ 6\%.$$

This method involves the solving of an awkward quadratic A simpler method is to assume η = 0 85, find full-load copper losses, thence total losses, input and efficiency Now go back and insert this value for η instead of the assumed 0·85, and obtain a more correct value as a result Extending this method *ad infinitum*, the correct efficiency will be obtained In general, only one such correcting process is necessary

6. 24 7 amp (brush-drop introduces a complication) **7.** 88·6%.

EXAMPLES 21

1. (*a*) 13·3, (*b*) 90·4% **2.** 89%

3. Output $= \dfrac{18\,\text{lb} \times 1\ 5\,\text{ft} \times 2\pi \times 1440 \times 746}{33{,}000}$ watts

Input = 200 × 32 6 watts.

Efficiency $= \dfrac{18 \times 3 \times \pi \times 1440 \times 746}{33{,}000 \times 200 \times 32\ 6} =$ 85 or 85% *Ans*

4. B H.P	·88	1·75	2 61	3 45	4 28
Efficiency.	75%	78%	83%	85%	83%

EXAMPLES 22

1. The three running-down curves are drawn as N against t, and tangents are drawn at N = 1000, whence values for dN/dt are found for this speed

Now at 1000 r.p m., $\omega = \dfrac{1000}{0} \times 2\pi$ and $\dfrac{d\omega}{dt} = \dfrac{2\pi}{60} \cdot \dfrac{dN}{dt}$

Thus $W = I\omega\dfrac{d\omega}{dt} = I\dfrac{1000 \times 4\pi^2}{60^2} \times \dfrac{dN}{dt} = \dfrac{100}{9}\ I\ \dfrac{dN}{dt}$

From the curves, we have for dN/dt in the three cases (a) unexcited = 38, (b) excited = 66, and (c) excited and loaded = 95 4.

Hence W = (a) 422 I, (b) 733 I, and (c) 1060 I

Now the added load in case (c) is 1·8 amp × 178 volts = 320 watts.

Thus 1060 I − 733 I = 327 I = 320 watts, whence I = 0·98 kg-mt²

Now friction loss = loss in (a) = 422 I = *413 watts*, and core loss = loss in (b) − loss in (a) = 311 I = *304 watts*

Energy of rotation $= \frac{1}{2} I\omega^2$

$$= \frac{0\ 98 \times 1000^2 \times 4\pi^2}{2 \times 9\ 81 \times 60^2} = 555 \text{ kg-mts.}$$

2. I = 225 kg-mts², E = 180,000 kg-mts **3.** 67 5 kW.

4. (a) 1·5 kW, (b) 1 53 × 10⁵ kg-mts² **5.** 74 4% (dynamo iron and friction losses included with the motor losses)

EXAMPLES 23

5. 1 222 grm-cm

EXAMPLES 24

1. (a) 52 55 b h p, (b) 182 amp **2** 57 1 amp **3.** 110·5 amp.
4. 383 amp **5.** 563 amp **6.** At eff of 85%, 85 2 amp, 50 h.p
7. 58 4 h p **8** Motor eff = 85%, pump eff = 70%, 22 2 kW.
9. (a) 100 h p, (b) 70%, (c) 85% Units per ton = 0 85.
10. At gear eff of 60% and motor eff of 85%, current 19 amp

EXAMPLES 25

1. Lap 1 — 24 — 3 — 26 — 5 — 28

Wave 1 — 24 — 47 — 70 — 93 — 116 — 139 — 162 — 185 — 22.

3. Conductors 484, 6 per slot in 81 slots, 2 idle conductors Winding wave, with pitch of 81 Slots about ·725 in × 1·25 in
4. Try —Conductors 654, 16 per slot in 41 slots, 2 idle conductors Winding pitch, 163, commutator segments, 164, i.e two turns per coil
5. 466 conductors, wave wound, 12 per slot, 2 idle Table—

F.	*B*	*F*	*B*	*F.*
1	118	235	352	
3	120	237	354	
5	122	239	356	

6. Conductors, 720, pitches, 121 and 119, segments, 360.
7. A/B = 1 675/1, B iron loss greater. **8.** Slots about 10 × 48 mm with conductors about 16 × 4 mm.

EXAMPLES 26

1 (*a*) 218 (220 will not suit a wave winding), (*b*) 880 **2.** 1005 **3** 40,600 lines per sq in **5** 83 4 × 10^3 lines/sq in **6** 600 r p m, 690 kW

EXAMPLES 27

1 26·7 lb -ft **2.** (*a*) 61 6 lb -ft, (*b*) 82 lb **3.** 21 b h p

4. Output watts = 20 × 746 Input watts = $\frac{20 \times 746}{0\ 84}$

Full-load current = $\frac{20 \times 746}{0\ 84 \times 230}$ = 77 3 amp

$$\text{R P M} = \frac{E \times 10^8 \times 60}{\Phi Z} = \frac{E \times 10^2}{\Phi_m \times 18} \quad (\Phi_m = \text{flux in megalines})$$

Input amps	RI drop	E volts	Φ 10^6 lines	R P M N	$M = \frac{60E}{N}$	$T = 1174MI_a$ lb ft	Total h p $= EI_a/746$
20	4 4	225 6	1 03	1205	11 13	26 18	6 0
40	8 8	221 2	1 67	736	18 02	88 74	11 84
60	13 2	216 8	2 08	580	22 42	158 3	17 45
77 3	17 0	213 0	2 36	502	25 15	231 3	22 06
80	17 6	212 4	2 39	494	25 82	243 2	22 80

5.

Per cent full load	25	50	75	100	125
R P M	1482	1466	1449	1431	1413

6. 210 r p m (change of armature resistance neglected) **7** 6 36 ohms **8** 1159 r p m **9** 18 85 m p h, 8 9 m p h, 51/21 **10.** 42 75 amps, (*a*) 83·31 amp, (*b*) 39·42*a* **11.** 83 2 lb -ft **12** Assuming equal drops and flux proportional to field current, I = 38 7 amp and N = 772 r p m **13.** 4 85%, allowing 2 volt brush drop, assuming (*a*) straight line magnetization curve in neighbourhood of full-load, (*b*) no armature demagnetizing reaction and (*c*) no temperature change effects upon resistances **14.** (*a*) 917·7 r.p m, 77 2 lb -ft., (*b*) 746 3 r p m, 174·2 lb -ft **15.** 0 867 ohms, 1130 watts **16.** (*a*) 2 467 ohms, (*b*) 420 r p m **17.** (*a*) 1540 r p m., (*b*) 3 75% **19.** 163·2 r p m, ·4 watt **20.** 774 r p.m

EXAMPLES 28

1. 5·6% **3.** 736 volts

2.

Load amps	0	100	200	300	400	500	500	400	300	200	100
Term volts	454	420	387	343	295	220	120	70	43	23	8

4.

Load amp	0	100	200	300	400	500	600	650	650	600	500
Term. volts	614	575	538	491	449	392	310	241	200	139	91
Loads amp (*contd*)	400	300	200	100							
Terms volts (*contd*)	62	39	25	11							

5. 108 2 volts **6.** Five turns, i e. 2300 amp.-turns

EXAMPLES 29

4 (*a*) 23 6 amp and 36 4 amp at 236 3 volts , (*b*) 5·3
14 67 amp at 262 38 volts

EXAMPLES 30

1. $d = 0\ 05''$ **2.** Depth $= 0\ 71''$ **3.** Assuming over of $10''$, $I = 1{\cdot}216$ amp , $S = 3700$, and $d = 0\ 044''$ **4.** 5 Maximum possible $d =\ 0427''$ **6.** Three layers of 32 $0\ 5'' \times 0\ 13''$ bare or about $\cdot525'' \times\ 155''$ insulated **7.** $I = 2$ amp , $d = 0\ 06''$ covered **8.** Approximate curr $= 0\ 91$ amp No of turns $= 5000/0\ 91 = 5500$ Re coil $= 110/0\ 91 = 121$ ohms Resistance of a mean turn or $110/5000 = r_m$ For a rise of 40° C , the final temp be about 55° C , and the specific resistivity at this t will be $0\ 67\ (1 + 55 \times\ 004) = 0{\cdot}67 \times 1\ 22 = 0\ 817$ mi in. cube

If l_m = length of a mean turn, d_m = mean diameter of coil, $\Big\}\ l_m = \pi d_m$

a = net cross-section of conductor, all inch meas

$$\text{Then } r_m = \frac{110}{5000} = \frac{0\ 817\ d_m}{10^6 a}, \text{ whence } a = 0\ 117\ d_m\ 1$$

Assuming that this conductor, when covered, will h increased by about 20%, i e $= 0\ 14\ d_m\ 10^{-3}$ With a sp 0·785, the winding space becomes

$$\frac{5500 \times 0{\cdot}14\ d_m\ 10^{-3}}{0\ 785} = 0\ 98\ d_m$$

But winding space also $= 7''\ (d - 6{\cdot}75'')$, and by equatin we obtain $d_m = 7\ 85''$, and net $a = 0\ 000914$, or diam $= 0\ 034''$ Hence use 21 S W G. Overall diameter of about $9''$ **9.** 4 turns per coil **10.** Suggest 1/ 036, **12.** 57,500 amp -turns **13.** (*a*) 0·172 cm ; (*b*) 2204 turn ohms , (*d*) 2·95 amp **14.** 45,900 **15.** 5460 **16.** 5 turns , 0 235 sq cm

EXAMPLES 31

1. 9200 **2** Time for commutation $= T =$ time to brush width If S = number of commutator segment r.p s , then time to travel one commut
b = number of commutator segments
$T = b/Sn$ Frequency of commutation $= f = 1/2T =$ is the coefficient of self-induction per coil and i_a - arma per coil to be commutated, then reactance voltage - E

$$= \frac{2\pi S n L i_a}{2b} = \frac{55 \times 11{\cdot}67 \times 0{\cdot}000153 \times 27}{1{\cdot}74} = 4\ 77\ \text{v}$$

3. $9{\cdot}95 \times 10^4$ lines **6.** $10\frac{1}{2}$ per pole.

EXAMPLES 32

1. 5 88, 4 5, 3·44, 2·63, 2 01, 1 54, 1 18, 0 9, 0 7, 0 53, ·0 4, 0 3 **2.** Using r = 0 6, I = 60, R's = 1 46, 0 88, 0 53, 0 31, 0 19, 0 11, 0 07, 0 04, 0 02, 0 017 **3.** 10 steps, 1 5, 1 05, 0 73, 0 52, 0 36, 0 25, 0 17, 0 12, 0 08, 0 075 **4.** 0·27, ·0 2, 0 15, 0 11, 0 085 **5** 5 legs, 1 cm wide, spaced 3·1 cm apart **6.** 4 86, 5 24, 2 44, 1 13, 0 53 0 246, 0 114 Total, 14 56 ohms **7.** (*a*) 10 ohms, (*b*) 33 3 r p m, (*c*) 2 26 ohms For materials for resistance elements, see *Electrical Engineers' Data Books*, Vol II (Benn) **8.** 83 33, 41 67, 25, 16 67, 11 92, 8 91, 6 95, 5·55 ohms **9.** R_1 = 15 71, r_1 = 3 99, r_2 = 3 37, r_3 = 2 86, r_4 = 2 42, r_5 = 2 06 **10.** Equal steps of 0 9 ohms each **11.** 1 07, 0·91, 0 77, 0 65, 0 55, total with motor, 4 7 ohms

EXAMPLES 33

1. Field alone		=460/6 amp = 76 66 ohms		
At 600 r p m,	460 × 5/6	=383·3,	for which I_f	=3 6, R =460/3 6=128
At 700	,, 460 × 5/7	=328 5	,	=2 4, R – 460/2 4=192
At 800	,, 460 × 5/8	=287 5,	,,	=1 8, R =460/1 8=255
At 900	,, 460 × 5/9	=255 5,	,,	=1 5, R=460/1·5=306
At 1000	, 460 × 5/10	=230,	,,	=1 3, R=460/1 3=354

Hence resistance units = 51·34, 64, 63, 51, and 48 ohms

2. 31 4 ohms **3.** 6 8 ohms of which 4 1ω will be subdivided

EXAMPLES 35

5 About 3¼d per unit

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